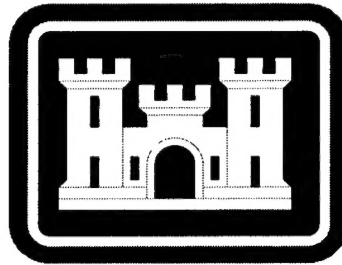


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**FY95 LIMITED ENERGY STUDY  
AREA B NITRIC ACID PRODUCTION FACILITIES**

**HOLSTON ARMY AMMUNITION PLANT  
KINGSPORT, TENNESSEE**



**U.S. ARMY CORPS OF ENGINEERS  
MOBILE DISTRICT**

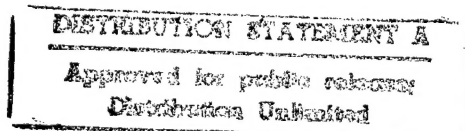
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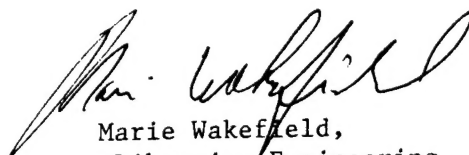


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**ENERGY CONSERVATION INVESTMENT PROGRAM (ECIP)**

**FY95 LIMITED ENERGY STUDY  
AREA B NITRIC ACID PRODUCTION FACILITIES**

**HOLSTON ARMY AMMUNITION PLANT  
KINGSPORT, TENNESSEE**

**CONTRACT NO. DACA01-94-D-0007  
DELIVERY ORDER NO. 004**

**[DTIC QUALITY INSPECTED 2]**

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# Executive Summary

## Introduction

In June 1995, Affiliated Engineers SE, Inc. (AESE) was retained by the Mobile District U.S. Army Corps of Engineers to perform a Limited Energy Study for Holston Army Ammunition Plant, Kingsport, Tennessee.

The field survey of existing conditions was completed in July 1995. The results of this field survey were subsequently tabulated and used to generate single line process flow diagrams on Autocad. A subsequent one day field survey was conducted in August 1995.

This report summarizes the results obtained from field investigation and the analysis of various alternative Energy Conservation Opportunities (ECO's).

ECO's were analyzed for suitability for the Energy Conservation Investment Program (ECIP) using the government's software package called Life Cycle Cost in Design (LCCID).

## Scope of Work

The Scope of Work developed by the U.S. Army Corps of Engineers gave the following tasks:

1. Perform a field survey to gather information on existing operating conditions and equipment at Holston Army Ammunition Plant, Area "B", Building 302 Nitric Acid Production Facilities.
2. Analyze the following ECO's:
  - a. Since 300 psig steam is available, revise air compressor turbine drive to steam. There may be variations on this ECO, such as using 300 psig steam exclusively (which might require a different turbine) or using steam (at 300 psig or at a reduced pressure) in the existing turbine to assist the electric motor.

- b. Use the product gas leaving the Air Preheater to generate steam. Depending on the pressure of the steam generated, the gas could be cooled to perhaps as low as 400°F. The steam thus generated could be used to drive (or assist in driving) the air compressor, or it could be used to vaporize ammonia, or for heating at the 302-B tank farm.
  - c. Identify and evaluate the possibility of water conservation at the cascade coolers and at other points in the process.
- 3. Suggest and analyze any additional ECO's representing savings potential as selected by A/E.
  - 4. Provide recommendations for implementation of ECO's into projects by SIR priority.
  - 5. Prepare a report to document the work performed, results, and recommendations.
  - 6. Provide documentation in the form of Project Development Brochures (PDB's) and DD Form 1391.

Building 302-B houses the processing facilities examined for ECO's.

#### Descriptions of ECO's

ECO No. 1 - Central Plant steam at 300 psig and 525°F is applied to a new 1200 hp compressor drive condensing single stage, Curtis type turbine. Exhaust steam at approximately 2.0 inches mercury vacuum is condensed in a new steam surface condenser using river water for heat rejection. The steam condensate from the condenser is returned to the central plant through condenser hotwell pumps.

Using projected operation of 1152 hours per year (4 days per month, 24 hours per day, 12 months per year), an annual electrical energy savings of 681,000 kWh/yr (2,324.97 mil. b/yr) and annual electrical demand charge savings of \$13,050 will be realized. However, 10,583 MMBtu/yr of increased steam energy from the existing steam plant will be required.

The life cycle cost analysis using the governments LCCID program indicates an increased owning and operating cost will result from this ECO. It does not qualify for energy conservation funding.

ECO No. 2 - A closed loop high temperature heat transfer fluid system is utilized to recover heat from product gas and convert the recovered heat to 100 psig saturated steam for use within the ammonia oxidation process (AOP) process, with excess steam delivered to existing distribution piping to offset steam produced at the central plant.

At projected operation of 1,152 hrs/yr, the calculated 3,446 MMBtu/yr steam savings, at the expense of 25,900 kWh/yr (885 MMBtu/yr) and associated increased demand charges, when used in the LCIDD program, produce total net discounted savings of \$13,175 for an estimated \$214,000 investment, and results in Savings to Investment Ratio (SIR) of 0.06. This ECO does not qualify for funding.

ECO No. 3 - Cooling water is presently used in the AOP process and then released to drain; this ECO provides reuse of the cooling water by returning it to a cooling tower where heat from the process will be rejected. The LCCID program results show \$71,024 discounted savings for a probable investment of \$43,708. The calculated SIR is 1.62.

ECO No. 4 - Uninsulated process vessels containing high temperature process fluid flows are to be insulated with jacketed calcium silicate pipe insulation. The \$5,408 probable cost of insulation will save about 135,000 kWh/yr of electricity at 1,152 hr/yr operation. The LCCID results show \$111,758 discounted savings and SIR = 20.67.

ECO No. 5 - As an adjunct to ECO No. 4, heat will be reclaimed from compressor drive turbines exhaust to produce 30 psig steam for use in ammonia vaporizers.

The probable investment cost of \$35,513 will save 664 MMBtu/yr of steam energy and 135,000 kWh/yr electrical energy during 1,152 hr/yr of operation. With associated annual electrical demand cost savings of \$2,585 per year, the LCCID program shows \$147,972 net discounted savings and SIR of 4.17.

ECO No. 6 - It was proposed to use the pure water condensed out of the compressed air and/or steam condensate from the ammonia vaporizers to increase mass flow through the

turbine and increase horsepower output. Although in theory this concept is viable for gas turbine engines, it was found to be infeasible for the uncontrolled turbine inlet conditions encountered in the AOP process.

ECO No. 7A - Recovered saturated steam at  $\pm 60$  psig is to be injected into the tailgas flow from the absorption column to increase mass flow through the tailgas heater and turbine which will in turn increase power output from the turbine and offset electrical energy consumed by the compressor motor. The recovery equipment will not require "cutting-in" to the highly corrosive product gas system. The incorporation of a heat exchange at this location, constructed of stainless steel, was determined not to be cost effective (see LCCID output for ECO 7).

The proposed modifications will save more than 200,000 kWh/yr of electrical energy and \$3,835 per year in electrical demand charges. The modifications render the process more independent from exterior energy sources. LCCID program results show \$157,657 net discounted savings and SIR of 1.54 on total investment of \$102,545.

#### Present Energy Consumption

There are four AOP lines at Building 302, each rated to produce 50 tons per day of 61 percent dilute nitric acid. To accommodate the present day demand for nitric acid in manufacturing explosives, intermittent operation of the production lines is employed. Production runs during each month constitute an aggregate single-line operation duration of  $\pm 1152$  hours per year.

During production, electrical energy and thermal energy (steam from the central plant) are consumed, and filtered water from the central water treatment facilities is used. Process operations at current production rates use this energy as follows:

Electricity -	457,053 kWh/yr 1,560 MMBtu/yr \$15,990 per year
Steam @ - Ammonia Vaporizer	823 MMBtu/yr \$3,208 per year
Cooling Water -	2.2 million gallons per year

### Technically Feasible ECO's

The results of the life cycle analysis of technically feasible ECO's, prioritized by descending savings-to-investment ratio, are as follows:

Priority	ECO No.	SIR	Total Investment	Simple Payback
1	4	20.67	\$ 5,408	0.74
2	5	4.17	35,513	3.64
3	3	1.62	43,708	9.00
4	7	1.54	102,545	9.97
5	2	0.06	214,388	150.00
6	1	-0.23	177,197	-42.03

### Synergistic Considerations

ECO No. 1 may be incorporated simultaneously with ECO No. 2 and/or ECO No. 3. ECO No. 1 is incompatible with ECO No. 5 and No. 7 since energy recovery in ECO No. 5 and No. 7 is primarily obtained from gas turbine exhaust gases which, in ECO No. 1, are not available. Combining ECO No. 1 with ECO No. 4 would negate the benefits from ECO No. 4 alone, and would increase the required heat rejection quantity at the cascade cooler.

ECO No. 2 is additionally compatible with either or both ECO No. 3 and ECO No. 4. Similarly, it is incompatible with ECO No. 5 and No. 7 for the same reasons stated above.

ECO No. 3 can technically be incorporated with any combination of the other ECO's.

ECO No. 4 can technically be incorporated with any combination of the other ECO's, and is an integral part of ECO's 5 and 7.

### Recommendations

Implementation of heat exchanger insulation should be completed immediately. The modest cost involved should be available from operation and maintenance funds. Both qualifying ECO's No. 5 and No. 7 include this insulation. Because ECO No. 7 provides greater independence from off-site utilities, it is recommended over ECO No. 5 which is economically more attractive.


Implementation of ECO No. 3 is also recommended, since it is economically attractive.

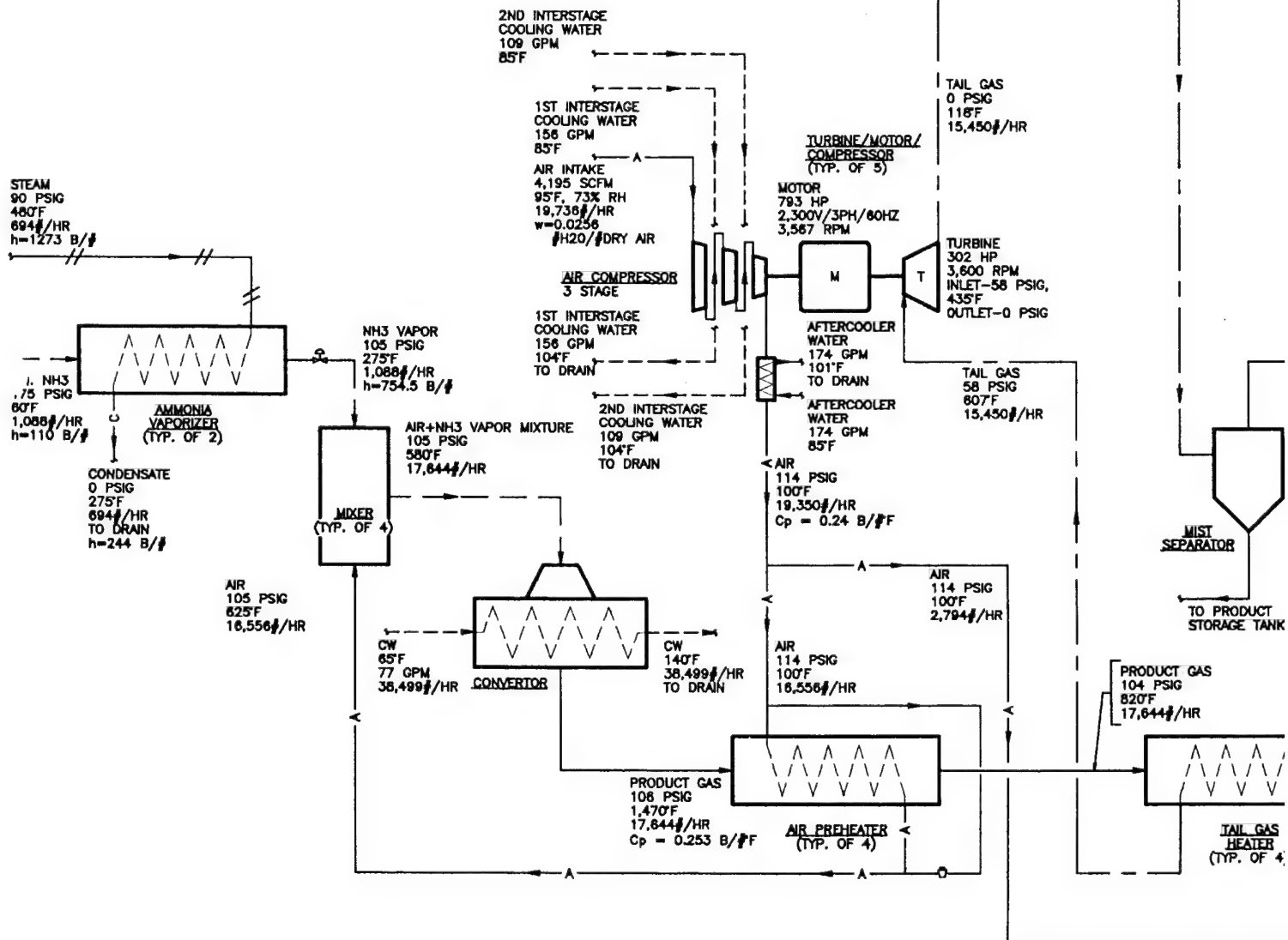
## History

Holston Army Ammunition Plant (HAAP) in Kingsport, Tennessee, manufactures explosives from raw materials. The facility comprises two separate areas designated Area "A" and Area "B".

At Area "B", Nitric Acid production facilities located in Building 302 include energy intensive AOP lines from which dilute nitric acid is obtained. The original chemical and mechanical equipment was placed in service in 1942, employing a process invented in 1935. Significant modifications have occurred over the extended life of the systems, and the current configuration is shown schematically in Figure 1.

**LEGEND**

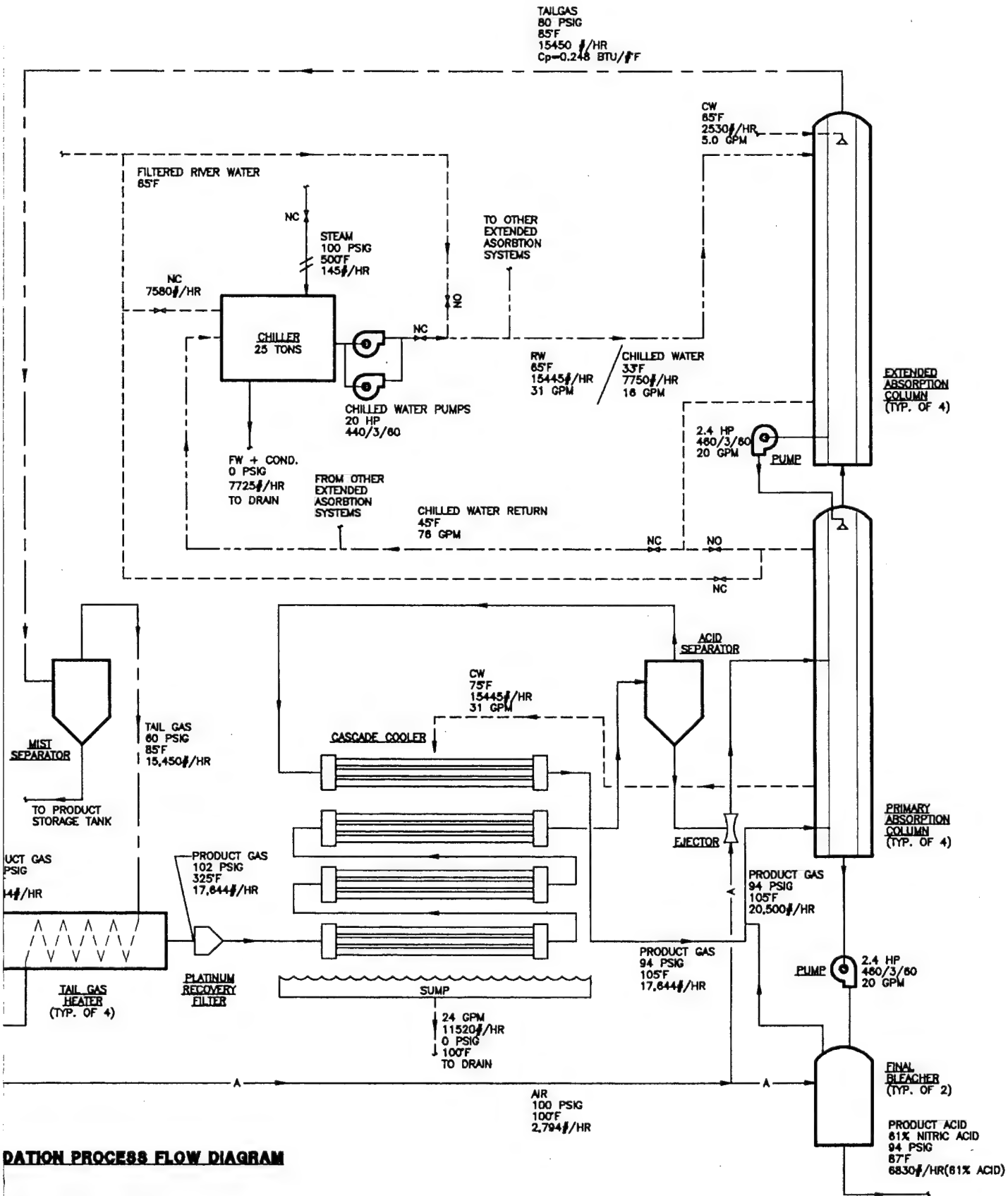
---	WATER
— A —	AIR
---	TAIL GAS
---	AMMONIA OR AMMONIA/AIR MIXTURE
---	PRODUCT OR PRODUCT GAS
—//—	STEAM
— C —	CONDENSATE
→	DIRECTION OF FLOW
	PUMP
---	CHILL WATER



**AMMONIA OXIDATION PROC**  
SCALE NONE

**EXISTING 9)**





**EXISTING SYSTEM**

## Problem Statement

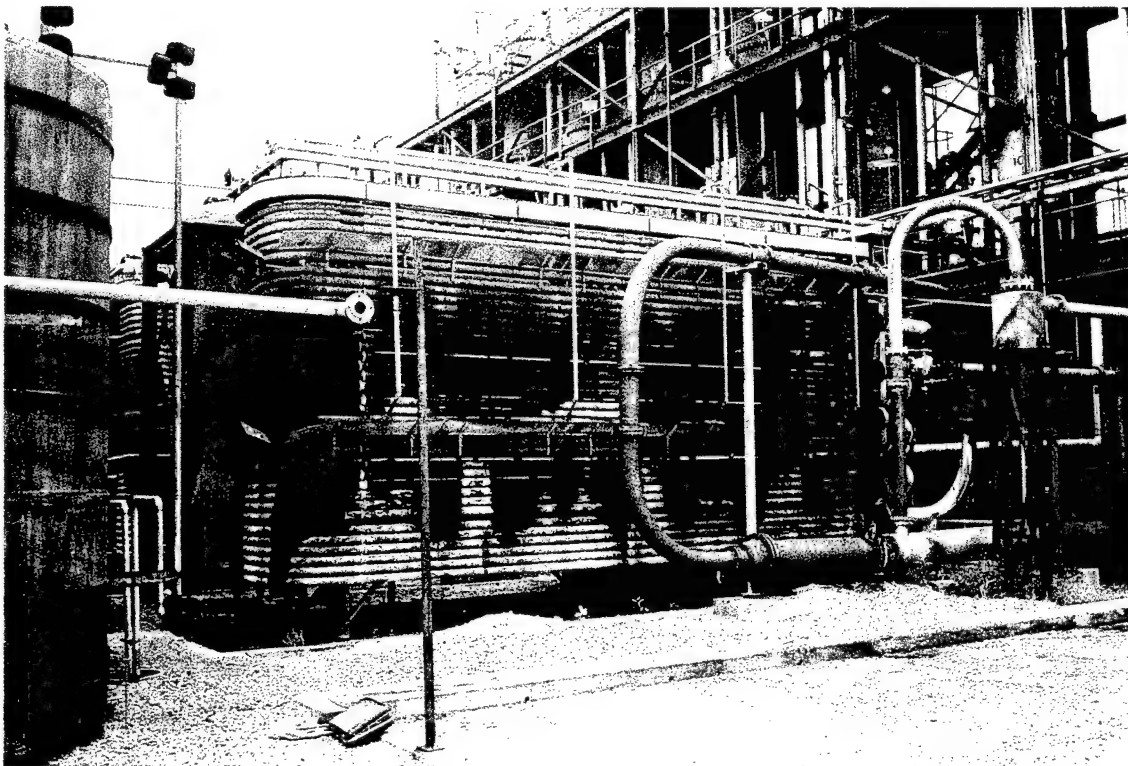
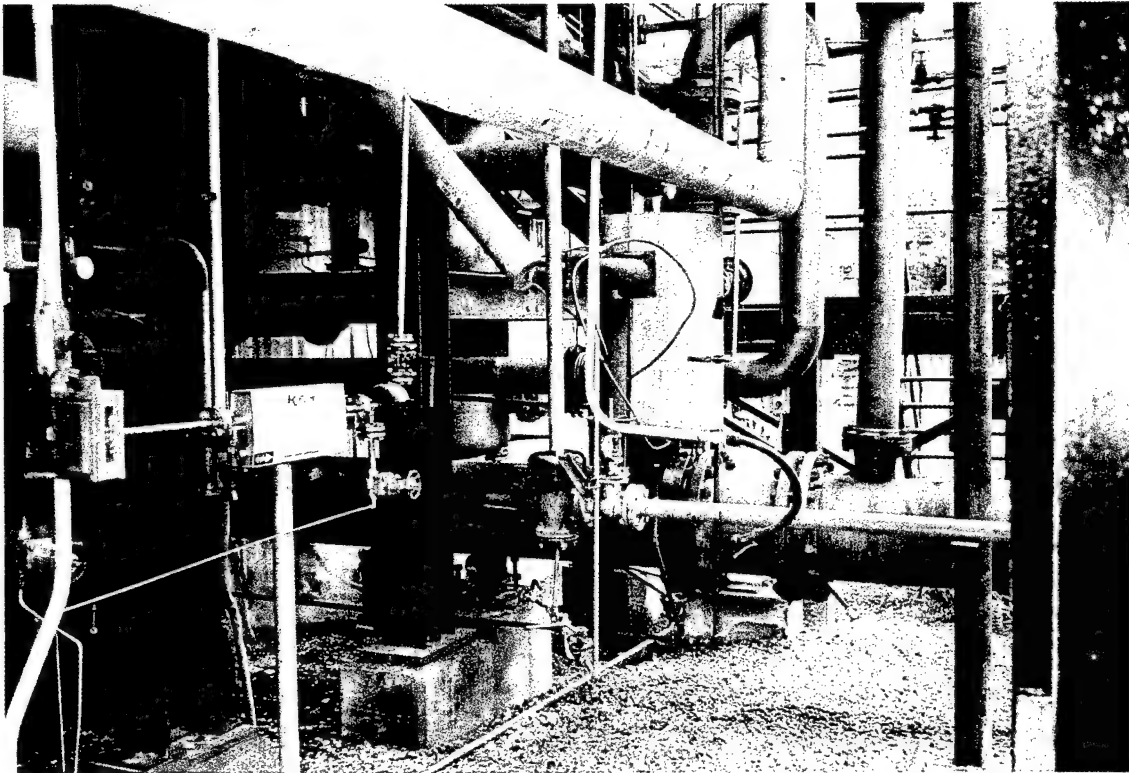
Demand by the military for explosives has declined in recent years, and continued progressively decreasing demand is forecast. Because plant mobilization to accommodate any increased military demand (i.e., renewed global conflict involving or supported by the United States) may be required on short notice, the production facilities must be maintained in a ready status.

Today's production demands are met by operating one or two of the four 50 ton/day oxidation process lines in Building 302 four continuous 24-hour days, with monthly equivalent single line operation totaling 96 hours.

Equipment providing heat rejection at the cascade cooler and the water chiller employs technology inconsistent with today's emphasis on energy efficiency. Insulation on piping and pressure vessels containing fluids at elevated temperatures is essentially non-existent.

Photographs included as Figure 2 show some of these conditions. All of the steam delivered to the process equipment is discharged to drain as steam condensate. Most of the filtered river water used for process heat rejection is discharged to drain after circuiting the heat exchange equipment.

Figure 2



## Purpose of the Study

The purpose of this study is to identify and evaluate the technical and economic feasibility of process or equipment modifications pursuant to conservation of energy and reduction of water consumption at the Ammonia Oxidation Process Facilities in Building 302, Area "B". An adjunct requirement is to avoid proposed modifications which would impose additional maintenance and operation requirements.

The following ECO's specifically identified by scope documents, were investigated:

1. Convert air compressor drive turbine from tailgas to steam or to steam augmentation.
2. Recover heat from product gas leaving the air preheater to produce steam.
3. Water conservation.

Additional ECO's selected by the A/E to be studied include the following:

1. Insulate heat exchangers and tailgas piping.
2. Install preformed plate heat exchangers inside insulation on air preheater and tailgas heater vessels for heat recovery to a 30 psig steam system.
3. Inject air compressor intercooler and aftercooler condensate and steam condensate from the ammonia vaporizer into tailgas entering compressor drive turbine for increased power.

## Study Approach

Observations of the installation were made during field surveys conducted July 5, 1995 through July 7, 1995 and again on August 18, 1995. To further establish the A/E's understanding of the chemical processes involved, and the energy associated with the chemical reactions, two reports prepared by other consultants were reviewed. From the final report titled Limited Energy Studies by EMC Engineers, Inc. dated August 1992, a "Process Energy Inventory" tabulation for Nitric Acid Manufacturing, Building 302-B, apparently excerpted from Technical Report No. HDC-39-77 was obtained. The table is presented in the appendix under "Reference Material". The formulae for essential chemical reactions for the production of Nitric Acid by the oxidation of ammonia were obtained from Working Summary Report prepared by AAI Corporation dated December 1992.

The schematic of the AOP process included in the project Detailed Scope of Work was reconstructed to reflect existing system configuration confirmed during field surveys.

It was noted that data contained in the schematic of the AOP process from the scope documents and the previously referenced Process Energy Inventory from Technical Report No. HDC-39-77 apparently represented the system prior to installation in 1991 of four new air compressors manufactured by Joy Manufacturing Co., prior to installation in 1982 of the extended absorption columns, and prior to the installation in 1979 of the refrigerated water system (water chiller).

## Process Energy Inventory

A molal analysis of the chemical reactions was performed to determine constituents of the tailgas and to establish water vapor (and liquid) quantities required to be condensed and used as diluent for the product nitric acid. From this calculation and source material from compressor and turbine manufacturers literature, an "Existing System Process Energy Inventory" was developed. The manufacturer's literature is presented in the Appendix under "Reference Material" also included in "Reference Material" are tables, formulae, charts and excerpts from various documents used in the development of the energy and chemical analysis. Table 1 shows the inventory data, which was used to prepare the Ammonia Oxidation Process Flow Diagram/Existing System presented as Figure 1 herein. All ECO's were evaluated using this data for baseline comparison.

**TABLE 1. EXISTING SYSTEM PROCESS ENERGY INVENTORY**

Equipment	Heat Gain		Heat Rejected			Heat Recovered			Heat Lost		Remarks
	MBH	Source	MBH	Source	Destination	MBH	Source	Recipient	MBH	Waste Stream	
Ammonia Vaporizer	714.1	Stm. Syst.	149.2	Stm. Cond.	Drain				149.2	Drain	
Mixer	178.8 (177.9)	Air NH <sub>3</sub>									
Converter	7136.1	Reaction	2887.4	Reaction	River Water				2887.4	Drain	
Air Preheater			2902.9	Prod. Gas	Air & Atmos	2086.1	Prod. Gas	Air	816.8	Atmosph.	
Tailgas Heater			2211.4	Prod. Gas	TG & Atmos	2001.5	Prod. Gas	Tailgas	209.9	Atmosph.	
Cascade Cooler	4869.4	80% HNO <sub>3</sub> Reaction	2846.2	Prod. Gas & H <sub>2</sub> O Vapor Condens.	River Water Drain & Atmos				2846.2	Drain	
Absorption Columns	1217.3	20% HNO <sub>3</sub> Reaction	86.5	Prod. Gas & H <sub>2</sub> O Vapor Condens.	River Water				86.5	Drain	
Air Compressor	2018.2	Elect. Mtr	2750.6	H <sub>2</sub> O Vapor Condens.	River Water				2750.6	Drain	793 hp
Tailgas Turbine	768.2	Heat Recovered	2097.4	Turbine Exhaust	Atmos.	768.2			1329.2	Exh to Atmosph	302 hp
Final Bleacher			118.7	Product	Product	118.7	Product	Product			
Unaccounted Losses			673.9						673.9		
<b>TOTAL</b>	16724.2		16724.2			4974.5			11749.7		

## Assumptions

The following assumptions have been made:

1. A Molar products table based on a hydrocarbon fuel composition of  $(CH_2)_n$  will yield suitable results for the products of combustion of  $NH_3$  (ammonia), provided that the percentage of theoretical air is the same composition for the ammonia as the hydrocarbon. (Gas tables by Kennan and Kaye are sufficiently accurate).
2. Air temperature entering the mixer is automatically controlled at 625°F by mixing nominal 100°F, 115 psig air from the aftercooler with uncontrolled air leaving the air preheater.
3. Existing tailgas heater materials of high chrome iron are compatible with high temperature heat transfer fluids substituted for the tailgas.
4. Existing turbines operating on tailgas flow streams will have similar efficiency when operating on steam.



## Energy Conservation Opportunities

### ECO No. 1: Turbine Conversion to Steam

The existing turbines, manufactured by Dresser-Rand Steam Turbine and Motor Division, used to augment the electric motors driving the air compressors, were basically designed as steam turbines but are currently employed as gas turbines for recovery of energy contained in process tailgas. Based on energy balance documents furnished by the government, calculated shaft output with 15,450 lb/hr, 58 psig, 435° F gas at the turbine inlet is 347 hp with turbine exhaust to atmosphere. At conditions determined independently as work of this report, the calculated turbine output is 302 hp. Inlet temperatures are limited to 750° F maximum.

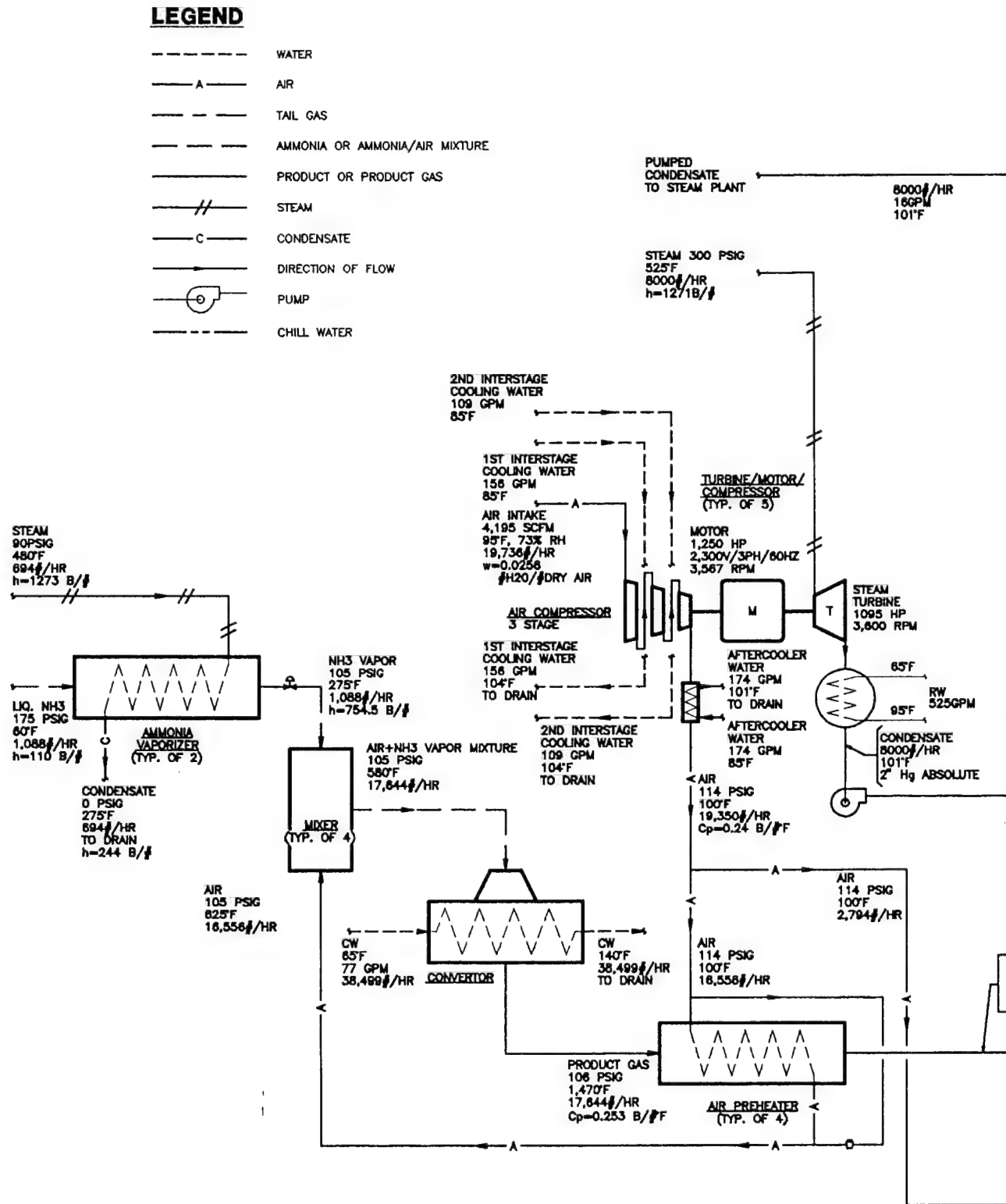
Replacement of the turbines with new 1,200 hp condensing type units to operate on the Thermodynamic Rankine Cycle with steam/water as the working fluid is proposed. Steam at 300 psig and 525° F from the central plant will be directed to the steam turbine. Turbine exhaust at 2.0 inch Hg vacuum will be condensed in a steam surface condenser using river water as the condensing medium. From the condenser, the condensate will be returned to the central plant by condenser hotwell pumps.

Performance of the Rankine Cycle System in the AOP process is indicated schematically in Figure 3 herein. Shaft energy produced will displace electric motor energy required to drive air compressors. Table 2 shows the energy inventory associated with ECO No. 1.

### ECO No. 2: Steam Produced from Product Gas

Introduction of liquid Dowtherm A heat transfer fluid into the existing tailgas heater vessel (liquid in place of tailgas) is proposed to recover heat from the product gas prior to its introduction to the cascade heater. The fluid, the eutectic mixture of diphenyl oxide and diphenyl, would then be pumped through a closed system in which the fluid would release heat in an unfired steam boiler vessel to produce steam at 100 psig and 30° F for use in AOP process equipment or for offsetting steam production in the central plant.

Figure 3



AMMONIA  
SCALE: NONE

STEAM



TABLE 2. ECO NO. 1 PROCESS ENERGY INVENTORY

Equipment	Heat Gain		Heat Rejected			Heat Recovered			Heat Lost		Remarks
	MBH	Source	MBH	Source	Destination	MBH	Source	Recipient	MBH	Waste Stream	
Ammonia Vaporizer	714.1	Stm. Syst.	149.2	Stm. Cond. to Drain					149.2	Drain	
Mixer	178.8 (177.9)	Air NH <sub>3</sub>									
Converter	7136.1	Reaction	2887.4	Reaction	River Water				2887.4	Drain	
Air Preheater			2902.9	Prod. Gas	Air & Atmos	2086.1	Prod. Gas	Air	816.8	Atmosph.	
Tailgas Heater			704.0	Prod. Gas	TG & Atmos				704.0	Atmosph.	
Cascade Cooler	4869.4	80% HNO <sub>3</sub> Reaction	4163.4	Prod. Gas & H <sub>2</sub> O Vapor Condens.	River Water Drain & Atmos				4163.4	Drain	
Absorption Columns	1217.3	20% HNO <sub>3</sub> Reaction	86.5	Prod. Gas & H <sub>2</sub> O Vapor Condens.	River Water				86.5	Drain	
Air Compressor	2786.8	Turbine	2750.6	H <sub>2</sub> O Vapor Condens.	Atmos. River Water				2750.6	Atmos. Drain	
Steam Turbine	10525.0	Steam from Steam Plant	13312.0	Turbine Exhaust	Condens. & River Water	526.5	Stm. Cond.	Stm. Plnt	12785.5	Stm Surf. Cond.	12840 #/hr Steam Rqd. @ 300 psi @ 525° F - 1095 hp
Final Bleacher			118.7	Product	Product	18.7	Product	Product			
Stack Loss			95.8	Tailgas	Atmos.				95.8	Atmos.	
Unaccounted Losses			89.1						89.1		
<b>TOTAL</b>	27259.6		27259.6			2731.3			24528.3		

This ECO would eliminate the availability of high energy tailgas use in the existing air compressor gas turbine. Release of the low temperature tailgas to atmosphere (from 58 psig) will be a source of objectional noise. It integrates ideally into the proposed system in ECO No. 1. Table 3 shows the energy inventory associated with ECO No. 2, and Figure 4 represents the AOP process with ECO No. 2 incorporated.

#### ECO No. 3: Water Conservation at Chiller and Cascade Coolers

Filtered river water discharged to drain, is 20°F to 80°F above river water temperature. No contaminants are introduced into the flow streams at Building 302. It is proposed to evaporatively cool the water in an induced draft cooling tower and return it to the heat rejection equipment so that costs at the Central Water Treatment Plant can be reduced. Primarily, savings will be derived from reduced demand for aluminum sulfate and hydrated lime in the flocculation process of the filter plant.

Table 4 and Figure 5 represent the AOP process with proposed ECO No. 3 water conservation incorporated.

#### ECO No. 4: Insulate Heat Exchangers

Heat is released to the atmosphere by radiation and convection from the dull bare metal surface of the nominal 18 inch diameter pressure vessels and 6 inch diameter tailgas piping. Standard high temperature calcium silicate pipe insulation with protective metal jacket is to be installed to increase recovered energy used in the air compressor gas turbine drive unit. Proposed insulation thickness is 1 inch.

AOP process parameters with proposed insulation are indicated in Table 5 and in Figure 6 herein.

#### ECO No. 5: Insulated Heater Surfaces with Low Pressure Steam Recovery

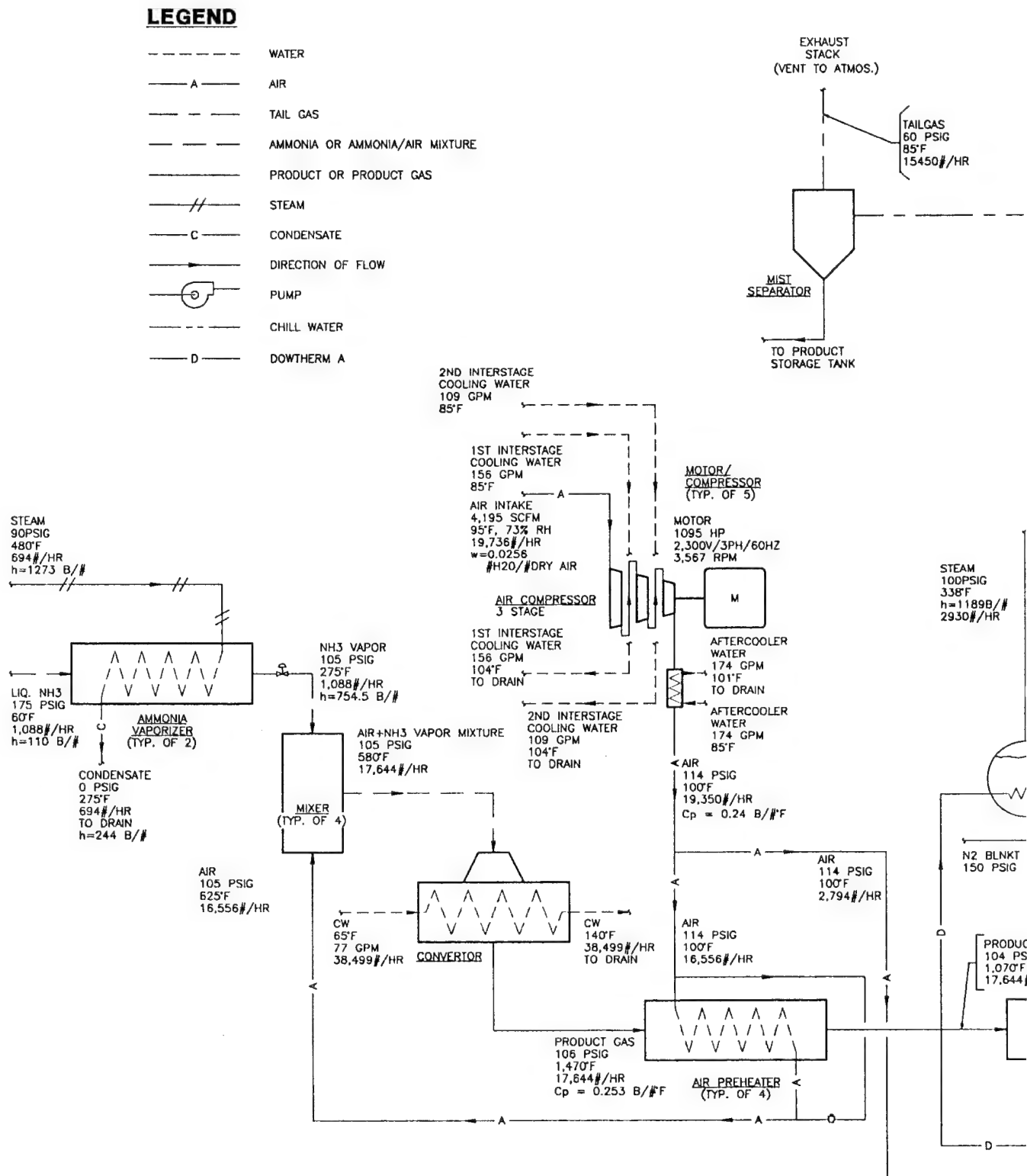
This ECO is an adjunct to ECO No. 4 - Insulate Heat Exchangers. Plant steam will still be required for production and process startup, but approximately 80% of steam used in the ammonia vaporizer will be derived from recovered energy.

A new 30 psig steam/condensate system, is proposed. The 30 psig steam is produced in a waste heat steam generator (WHSG) to extract heat from the 480°F turbine exhaust gas. Exhaust gas (tailgas) exiting the WHSG is discharged to atmosphere.

TABLE 3. ECO NO. 2 PROCESS ENERGY INVENTORY

Equipment	Heat Gain		Heat Rejected			Heat Recovered			Heat Lost		Remarks
	MBH	Source	MBH	Source	Destination	MBH	Source	Recipient	MBH	Waste Stream	
Ammonia Vaporizer	714.1	Stm. Syst.	149.2	Stm. Cond. to Drain					149.2	Drain	
Mixer	178.8 (177.9)	Air NH <sub>3</sub>									
Converter	7136.1	Reaction	2887.4	Reaction	River Water				2887.4	Drain	
Air Preheater			2902.9	Prod. Gas	Air & Atmos	2086.1	Prod. Gas	Air	816.8	Atmosph.	
		10% HNO <sub>3</sub> Reaction			Dowtherm & Atmos.						±2690 #/hr saturated steam produced @ 100 psig
Dowtherm Heater	608.7		3234.6	Prod. Gas		2990.8	Prod. Gas	Dowtherm	243.8	Atmosph.	
Cascade Cooler	4260.5	70% HNO <sub>3</sub> Reaction	1949.4	Prod. Gas & H <sub>2</sub> O Vapor Condens.	River Water Drain & Atmos				1949.4	Drain	
Absorption Columns	1217.3	20% HNO <sub>3</sub> Reaction	86.5	Prod. Gas & H <sub>2</sub> O Vapor Condens.	River Water				86.5	Drain	
Air Compressor	2786.8	Elect. Meter	2750.6	H <sub>2</sub> O Vapor Condens.	River Water				2750.6	Atmos. Drain	1095 hp
Final Bleacher			118.7	Product	Product	118.7	Product	Product			
Stack Loss			95.8	Tailgas	Atmos.				95.8	Atmos.	
Unaccounted Losses			2549.3						2549.3		
<b>TOTAL</b>	16724.4		16724.4			5195.6			11528.8		

Figure 4



AMMONIA OXID/  
SCALE NONE

DOWT





TABLE 4. ECO NO. 3 PROCESS ENERGY INVENTORY

Equipment	Heat Gain		Heat Rejected			Heat Recovered			Heat Lost		Remarks
	MBH	Source	MBH	Source	Destination	MBH	Source	Recipient	MBH	Waste Stream	
Ammonia Vaporizer	714.1	Stm. Syst.	149.2	Stm. Cond. to Drain					149.2	Cooling Tower	
Mixer	178.8 (177.9)	Air NH <sub>3</sub>									
Converter	7136.1	Reaction	2887.4	Reaction	River Water				2887.4	Cooling Tower	
Air Preheater			2902.9	Prod. Gas	Air & Atmos	2086.1	Prod. Gas	Air	816.8	Atmosph.	
Tailgas Heater			2211.4	Prod. Gas	TG & Atmos	2001.5	Prod. Gas	Tailgas	209.9	Atmosph.	
Cascade Cooler	4869.4	80% HNO <sub>3</sub> Reaction	2846.2	Prod. Gas & H <sub>2</sub> O Vapor Condens.	River Water Drain & Atmos				2846.2	Cooling Tower	
Absorption Columns	1217.3	20% HNO <sub>3</sub> Reaction	86.5	Prod. Gas & H <sub>2</sub> O Vapor Condens.	River Water				86.5	Cooling Tower	
Air Compressor	2018.2	Elect. Meter	2750.6	H <sub>2</sub> O Vapor Condens.	River Water				2750.6	Cooling Tower	793 hp
Tailgas Turbine	768.2		2097.4			768.2			1329.2	Exh. to Atmosph	302 hp
Final Bleacher			118.7	Product	Product	118.7	Product	Product			
Unaccounted Losses			673.9						673.9		
<b>TOTAL</b>	<b>16724.2</b>		<b>16724.2</b>			<b>4974.5</b>			<b>11749.7</b>		


Figure 5

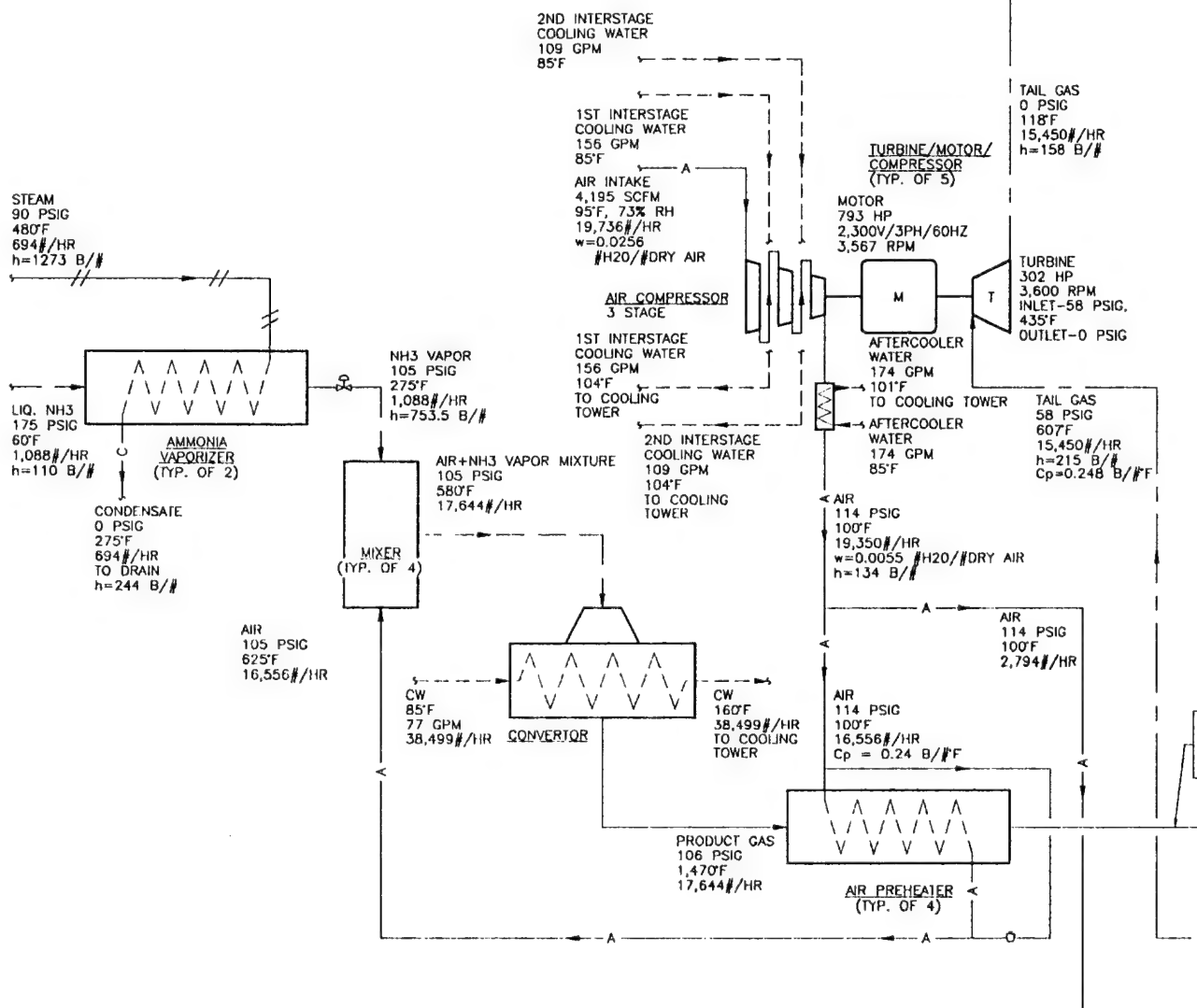
## COOLING TOWER

### DATA

566 GPM  
108°F EWT  
85°F LWT  
76°F W.B.  
85000 CFM FAN  
Ø15 HP  
6 GPM BLOWDOWN  
12 GPM MAKEUP

### LEGEND

----	WATER
— A —	AIR
----	TAIL GAS
----	AMMONIA OR AMMONIA/AIR MIXTURE
----	PRODUCT OR PRODUCT GAS
—//—	STEAM
— C —	CONDENSATE
→	DIRECTION OF FLOW
	PUMP
----	CHILL WATER



AMMONIA  
SCALE: NONE

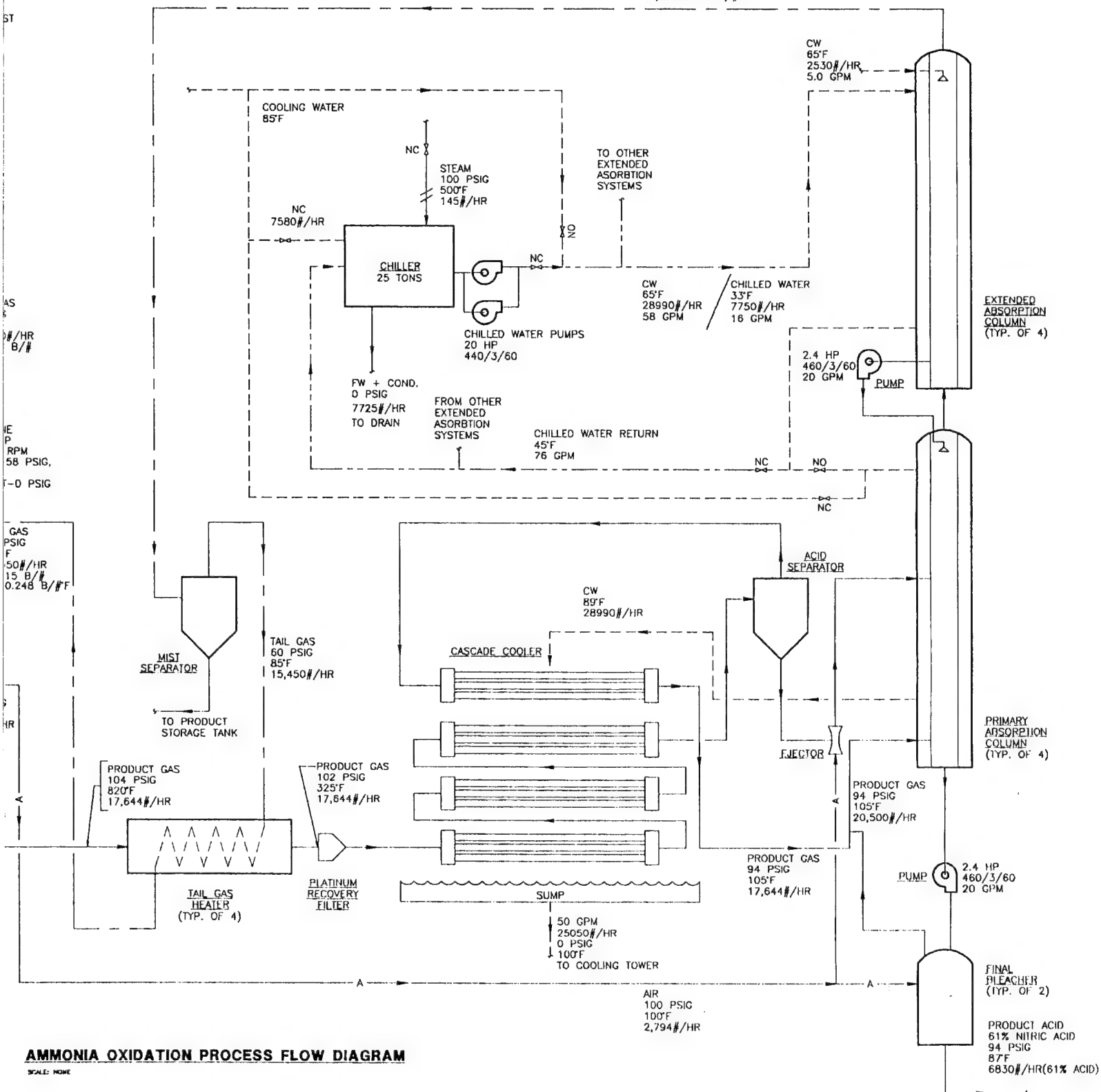
ST

AS  
B/#IE  
P  
RPM  
58 PSIG,  
F-D PSIGGAS  
PSIG  
F  
50#/HR  
15 B/#  
0.248 B/#F

HR

A

TAILGAS  
80 PSIG  
85°F  
15450 #/HR  
 $C_p=0.248$  BTU/#F



ECO NO. 3


INCORPORATE COOLING TOWER

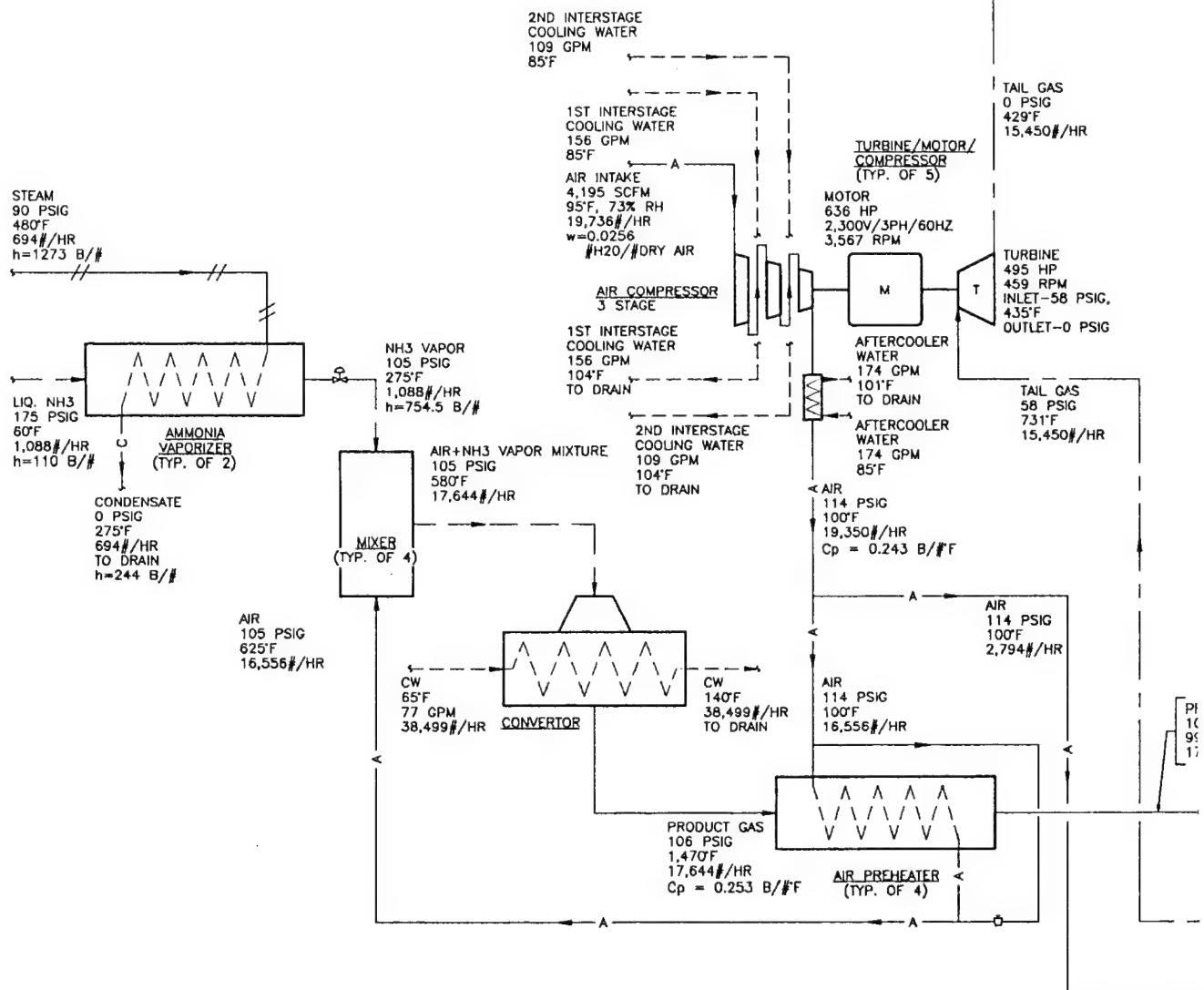
TABLE 5. ECO NO. 4 PROCESS ENERGY INVENTORY

Equipment	Heat Gain		Heat Rejected			Heat Recovered			Heat Lost		Remarks
	MBH	Source	MBH	Source	Destination	MBH	Source	Recipient	MBH	Waste Stream	
Ammonia Vaporizer	714.1	Stm. Syst.	149.2	Stm. Cond. to Drain					149.2	Drain	
Mixer	178.8 (177.9)	Air NH <sub>3</sub>									
Converter	7136.1	Reaction	2887.4	Reaction	River Water				2887.4	Drain	
Air Preheater			2128.8	Prod. Gas	Air & Atmos	2086.1	Prod. Gas	Air	42.7	Atmosph.	
Tailgas Heater			2496.7	Prod. Gas	TG & Atmos	2473.6	Prod. Gas	Tailgas	23.1	Atmosph.	
Cascade Cooler	4869.4	80% HNO <sub>3</sub> Reaction	2092.1	Prod. Gas & H <sub>2</sub> O Vapor Condens.	River Water Drain & Atmos				2092.1	Drain	
Absorption Columns	1217.3	20% HNO <sub>3</sub> Reaction	86.5	Prod. Gas & H <sub>2</sub> O Vapor Condens.	River Water				86.5	Drain	
Air Compressor	1618.6	Elect. Meter	2750.6	H <sub>2</sub> O Vapor Condens.	River Water				2750.6	Drain	636 hp
Tailgas Turbine	1168.2	Recovered Heater	2582.1	Tailgas	Atmos.	1168.2			1413.9	Exh. to Atmosph	459 hp
Final Bleacher			118.7	Product	Product	118.7	Product	Product			
Unaccounted Losses			1432.5						1432.5		
TOTAL	16724.6		16724.6			5846.6			10878.0		

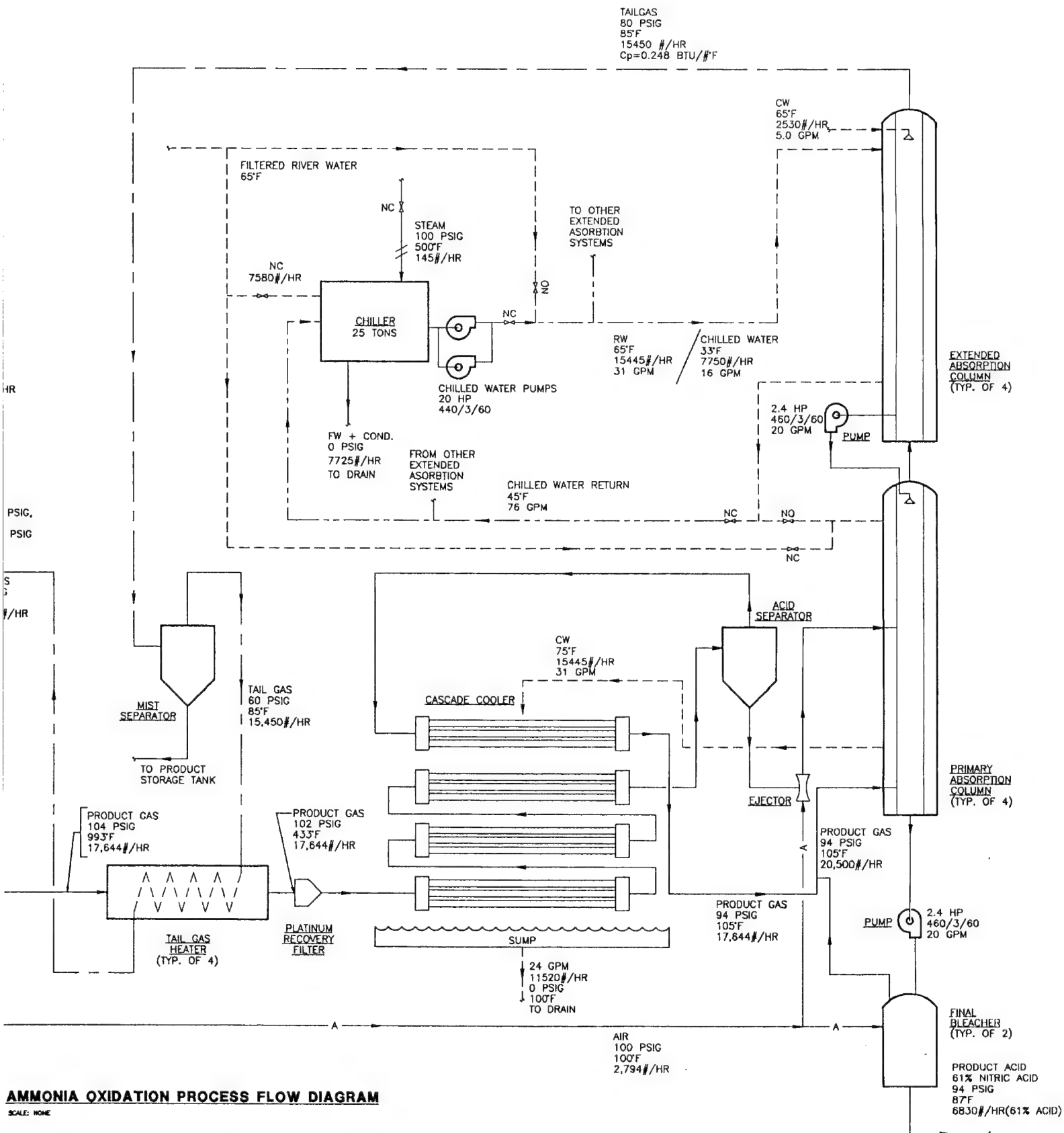
Figure 6

# **LEGEND**

---	WATER
— A —	AIR
---	TAIL GAS
---	AMMONIA OR AMMONIA/AIR MIXTURE
---	PRODUCT OR PRODUCT GAS
—//—	STEAM
— C —	CONDENSATE
→	DIRECTION OF FLOW
	PUMP
---	CHILL WATER



**AMMONIA O**  
SCALE: NONE



ECO NO.4

1" INSULATION ON HEATERS

Results of integrating this ECO into the AOP process are shown in Table 6 and Figure 7.

ECO No. 6: Water Injection at Gas Turbine

Not developed.

ECO No. 7: Recovered Steam Injected at Tailgas Turbine Inlet

Recovery of relatively pure water obtained from air compressor intercoolers and aftercoolers and from steam trap discharge at the ammonia vaporizer, all of which is presently discharged to waste, will be utilized for makeup to a waste heat steam generating system (WHSG) consisting of two recovery sections, one located in product gas stream leaving the platinum filter and the other in the wet gas stream leaving the turbine, and a steam separator vessel.

Additional boiler water makeup (approximately 10%) from the steam plant will augment the recovered water. Steam from the WHSG will be introduced into the hot tailgas from the tailgas heater to increase turbine output and offset electrical load of the compressor drive motor, and will be discharged to atmosphere along with the tailgas.

Introduction of the steam into the tailgas will be made at a sufficient distance upstream of the turbine inlet, in the existing 6 inch diameter standard black iron piping. The WHSG section in the product gas stream will be constructed of high chromium stainless steel (400 series) for surfaces in contact with product gas. The wet gas WHSG section will be standard steel construction as offered by Clayton Industries, El Monte, CA.

AOP process parameters with the proposed steam injection system, incorporated with the insulation evaluated in ECO #4, are shown in Table 7 and Figure 8 herein.

TABLE 6. ECO NO. 5 PROCESS ENERGY INVENTORY

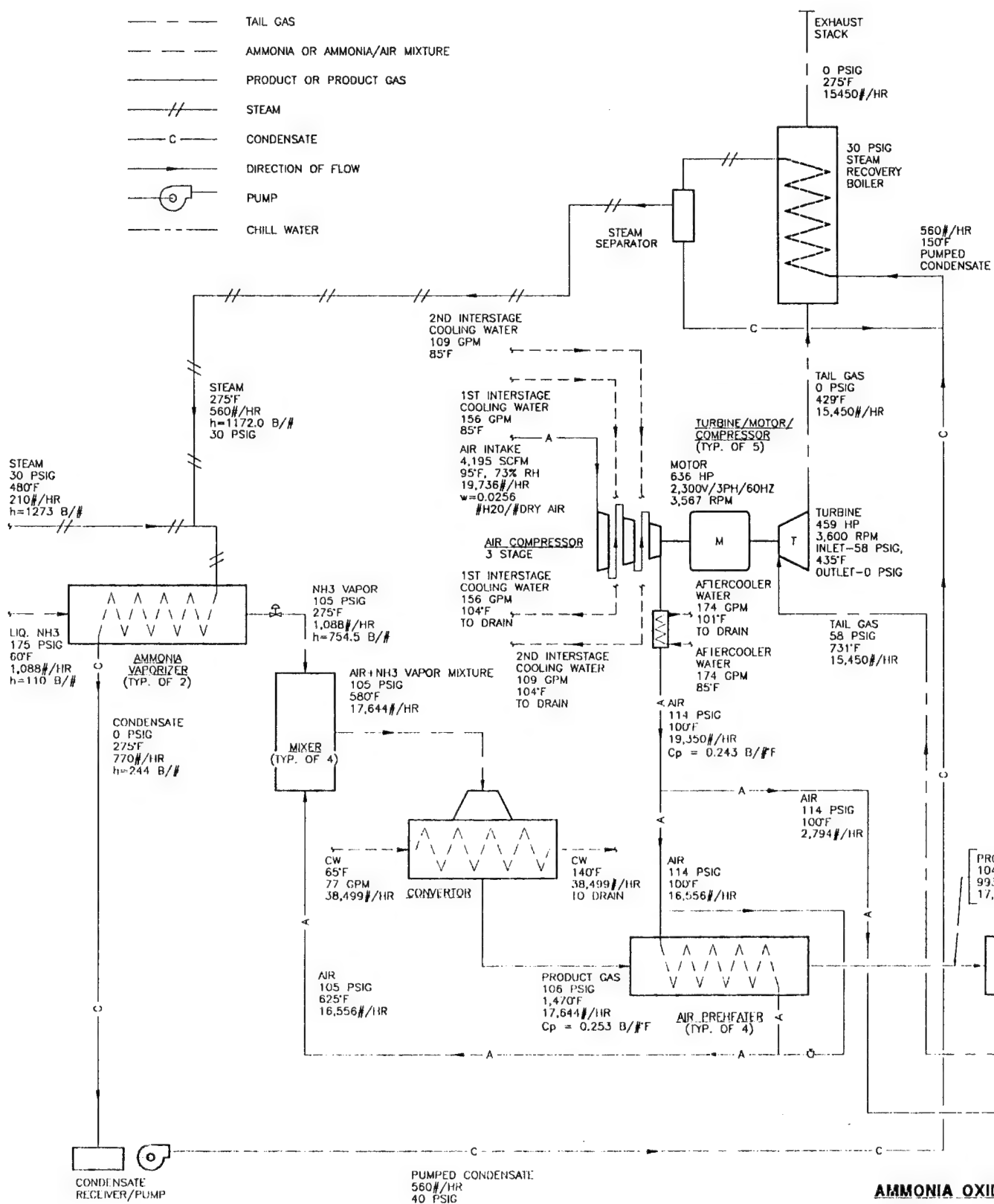
Equipment	Heat Gain		Heat Rejected			Heat Recovered			Heat Lost		Remarks
	MBH	Source	MBH	Source	Destination	MBH	Source	Recipient	MBH	Waste Stream	
Ammonia Vaporizer	714.1	L.P. Steam	149.2	Steam Cond.	Drain	149.2	Steam Cond.	LP Steam			
Mixer	178.8 (177.9)	Air NH <sub>3</sub>									
Converter	7136.1	Reaction	2887.4	Reaction	River Water				2887.4	Drain	
Air Preheater			2128.8	Prod. Gas	Air & Atmos	2086.1	Prod. Gas	Air	42.7	Atmosph.	
Tailgas Heater			2496.7	Prod. Gas	TG & Atmos & L.P. Stm	2473.6	Prod. Gas Prod. Gas	Tailgas L.P. Stm Syst.	23.1	Atmosph.	
Cascade Cooler	4869.4	80% HNO <sub>3</sub> Reaction	2092.1	Prod. Gas & H <sub>2</sub> O Vapor Condens.	River Water Drain & Atmos				2092.1	Drain	
Absorption Columns	1217.3	20% HNO <sub>3</sub> Reaction	86.5	Prod. Gas & H <sub>2</sub> O Vapor Condens.	River Water				86.5	Drain	
Air Compressor	1618.6	Elect. Meter	2750.6	H <sub>2</sub> O Vapor Condens.	River Water				2750.6	Drain	636 hp
Tailgas Turbine	1168.2	Recovered Heat	2582.1	Turb. Exh.	Stack	1758.3	Stack	L.P. Stm Syst.	823.8	Exh. to Atmosph	459 hp
Final Bleacher			118.7	Product	Product	118.7	Product	Product			
Unaccounted Losses			1432.5						1432.5		
<b>TOTAL</b>	16724.6		16724.6			6585.9			10138.7		



Figure 7

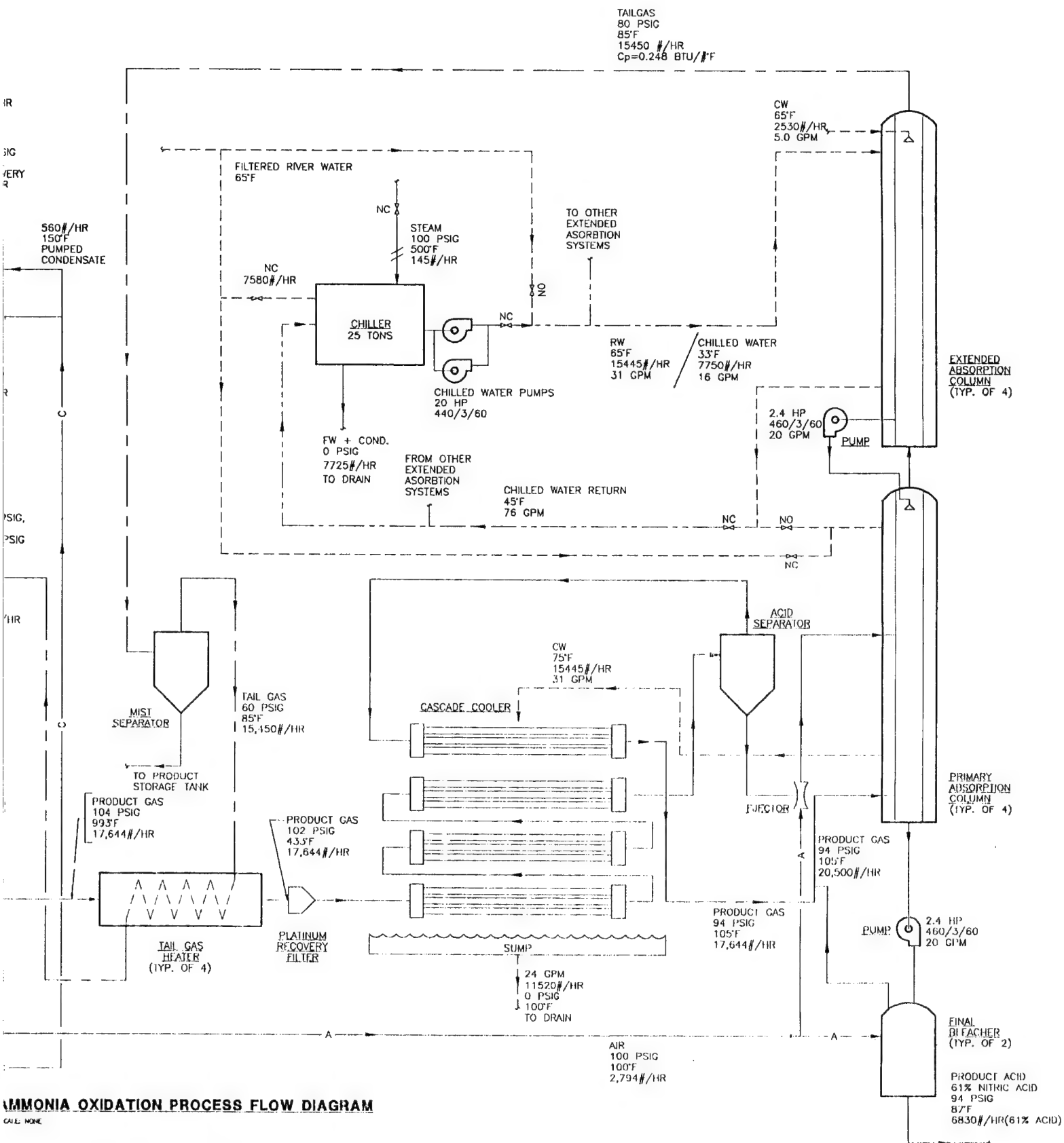
# LEGEND

- WATER
- A — AIR
- TAIL GAS
- AMMONIA OR AMMONIA/AIR MIXTURE
- PRODUCT OR PRODUCT GAS
- //--- STEAM
- C --- CONDENSATE
- DIRECTION OF FLOW
- ⊖ PUMP
- CHILL WATER



AMMONIA OXID  
SCALE: NONE

1" INS  
WITH LOW P



**AMMONIA OXIDATION PROCESS FLOW DIAGRAM**

DATE: NONE

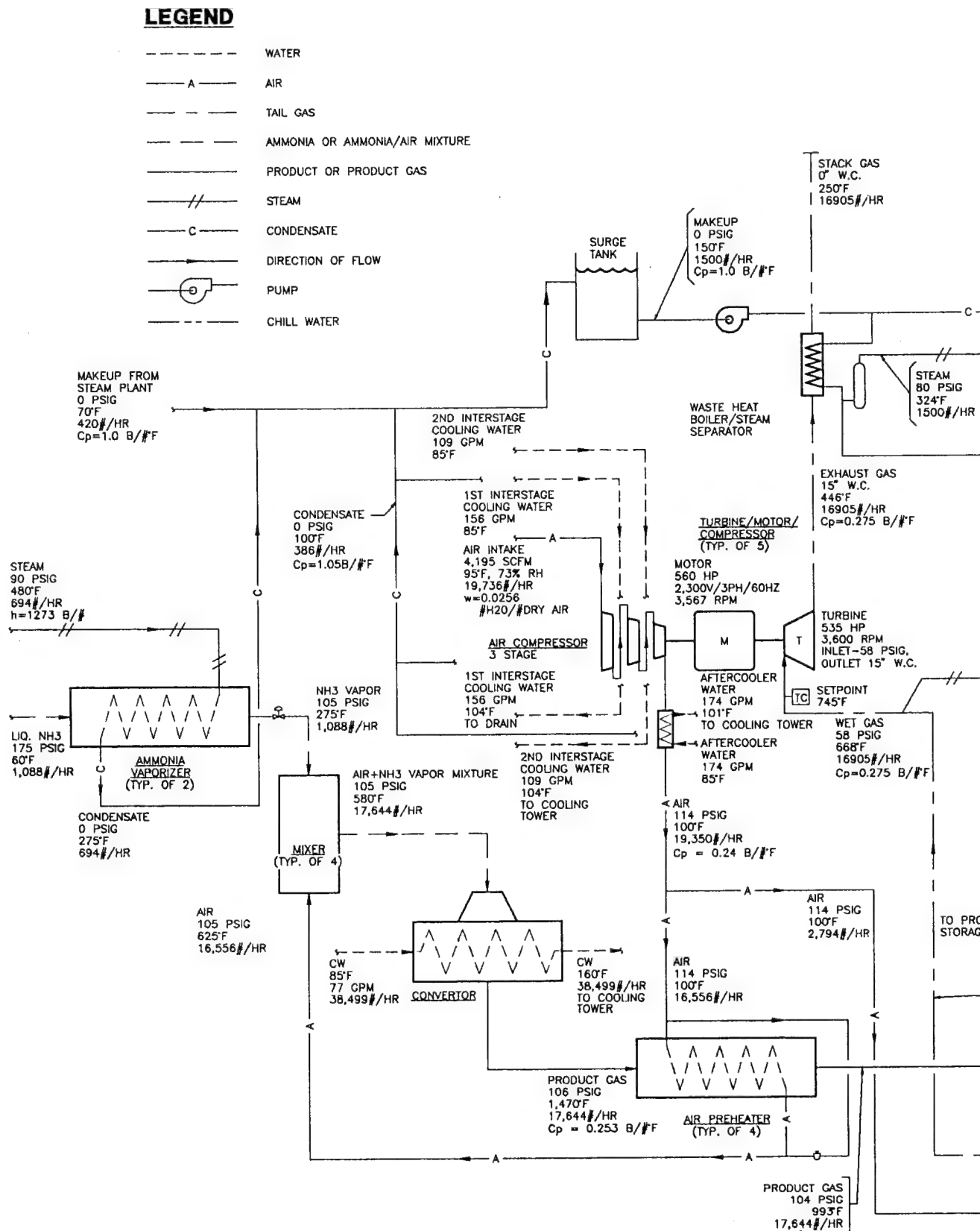
**ECO NO.5**

**1" INSULATION ON HEATERS  
WITH LOW PRESSURE STEAM RECOVERY**

TABLE 7. ECO NO. 7 PROCESS ENERGY INVENTORY

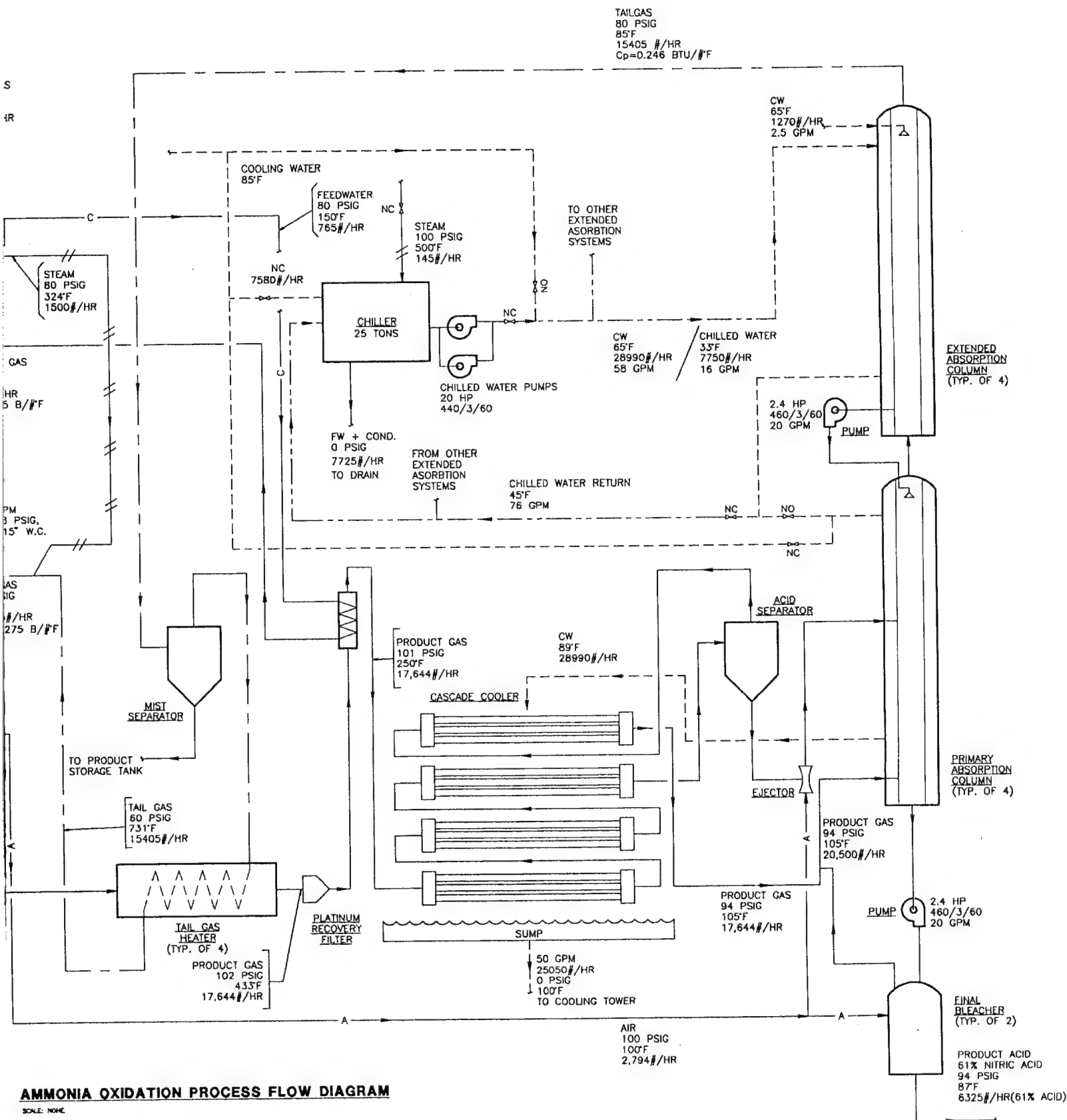
Equipment	Heat Gain		Heat Rejected			Heat Recovered			Heat Lost		Remarks
	MBH	Source	MBH	Source	Destination	MBH	Source	Recipient	MBH	Waste Stream	
Ammonia Vaporizer	714.1	L.P. Steam	149.2	Steam Cond.	Tailgas	149.2	Steam Cond.	Tailgas			
Mixer	178.8 (177.9)	Air NH <sub>3</sub>									
Converter	7136.1	Reaction	2887.4	Reaction	River Water				2887.4	Drain	
Air Preheater			2128.8	Prod. Gas	Air & Atmos	2086.1	Prod. Gas	Air	42.7	Atmosph.	
Tailgas Heater	2434.7	40% HNO <sub>3</sub> Reaction	2496.7	Prod. Gas & H <sub>2</sub> O Vapor Condens.	TG & Atmos	2473.1	Prod. Gas	Tailgas	23.1	Atmosph.	
Prod. Gas Recov. Boiler	608.7	10% HNO <sub>3</sub> Reaction	816.9	Prod. Gas	LP Steam	816.9	Prod. Gas	LP Steam			765 #/hr Steam
Wet Gas Boiler						837.9	Turb Exh.	L.P. Steam	956.6	Stack	786 #/hr Steam
Cascade Cooler	1826.0	30% HNO <sub>3</sub> Reaction	1275.2	Prod. Gas & H <sub>2</sub> O Vapor Condens.	River Water Drain & Atmos				1275.2	Drain	
Absorption Columns	1217.3	20% HNO <sub>3</sub> Reaction	86.5	Prod. Gas & H <sub>2</sub> O Vapor Condens. & Reaction	River Water				86.5	Drain	
Air Compressor	1425.2	Elect. Meter	2750.6	H <sub>2</sub> O Vapor Condens.	River Water				2750.6	Drain	560 hp
Tailgas Turbine	1361.6	Recovered Heat	3156.1	Turbine Exhaust	Wet Gas Recov. Blr	1361.6	Wet Gas	Air			535 hp
Final Bleacher			118.7	Product	Product	118.7	Product	Product			
Unaccounted Losses			859.0						859.0		
<b>TOTAL</b>	<b>16724.6</b>		<b>16724.6</b>			<b>7843.5</b>			<b>8881.1</b>		

Figure 8



AMMONIA O  
SCALE: NONE

STEAM/WAT  
HEATERS



## Calculations

Calculations for energy inventories throughout the product gas and tailgas flow streams were made using published data where available. Heat release from the exothermic reaction in the product gas stream, as indicated on flow diagrams and tables in the material furnished by the government and the operating contractor, was adjusted by application of principles and chemical values from several engineering handbooks. Excerpts from these handbooks are presented in the Appendix, section Reference Material.

Thermodynamic properties of steam and water vapor in air were obtained from "Thermodynamic Properties of Steam"; thermodynamic properties of air were obtained from "Gas Tables". Specific heat data for various gases and liquids were obtained from "Marks' Standard Handbook for Mechanical Engineers" and additional textbooks. Heat loss for bare and insulated pipes was obtained from insulation manufacturers catalogs. Thermodynamic properties of Dowtherm A heat transfer fluid were obtained from "Marks' Handbook" and from tabular data in Platecoil Catalog, Tranter, Inc. In general, where data was obtained from graphically presented material, the diagram is included in the Appendix with the detailed calculations.

Basic formulae, definitions, numerical values and results of calculations for process chemical and thermal parameters are presented in this section.

Detailed calculation sheets are included in Appendix.

## Calculations For: Pound Moles per Hour Delivered to Process

$$\text{NH}_3: \frac{\text{lbs/hr}}{\text{mol. wt}} = \frac{1088 \text{ lbs/hr}}{17.0307} = 63.88 \text{ \#-mol/hr}$$

Specific Humidity of Air/Vapor Mixture:

$$W = \frac{P_v R_\alpha}{(P_m - P_v) R_v}$$

Where:  $P_v$  = Vapor pressure of water @ 100° F dewpoint  
 $P_m$  = Air/vapor mixture pressure  
 $R_\alpha$  = Universal gas constant/mol. wt. of air  
 $R_v$  = Universal gas constant/mol. wt. of  $\text{H}_2\text{O}$

$$W = \frac{(0.9492 \text{ psia}) (1544/28.9644)}{(129.97 \text{ psia} - 0.9492 \text{ psia}) (1544/18.016)} = 0.0046 \text{ \#vapor/\#dry air}$$

Air/Vapor Mixture Mass Flow = 16556 lbs/hr

$$\text{H}_2\text{O}: \frac{16556 \text{ lbs/hr}}{1 + \frac{1}{0.0046 \text{ lbs/\# dry air}}} = 75.81 \text{ lbs/hr}$$

$$\frac{\text{lbs/hr}}{\text{mol. wt}} = \frac{75.81 \text{ lbs/hr}}{18.016} = 4.21 \text{ \#-mol/hr}$$

Dry Air Mass Flow = 16556 lbs/hr - 75.81 lbs/hr = 16480.19 lbs/hr

$$\text{N}_2: \frac{\text{lbs/hr x mol. fract}}{\text{mol. wt. air}} = \frac{16480.19 \text{ lbs/hr} (0.78084)}{28.9644} = 444.28 \text{ \#-mol/hr}$$

$$\text{O}_2: \frac{\text{lbs/hr x mol. fract}}{\text{mol. wt. air}} = \frac{16480.19 \text{ lbs/hr} (0.20948)}{28.9644} = 119.19 \text{ \#-mol/hr}$$

$$\text{A}_\text{R}: \frac{\text{lbs/hr x mol. fract}}{\text{mol. wt. air}} = \frac{16480.19 \text{ lbs/hr} (0.00934)}{28.9644} = 5.31 \text{ \#-mol/hr}$$

$$\text{Other: } \frac{\text{lbs/hr x mol. fract}}{\text{mol. wt. air}} = \frac{16480.19 \text{ lbs/hr} (0.00034)}{28.9644} = 0.19 \text{ \#-mol/hr}$$

TOTAL 568.97 \#-mol/hr

# COMBUSTION CALCULATIONS—MOLAL BASIS



L I N E	FUEL, O <sub>2</sub> , AND AIR PER UNIT OF FUEL					FLUE GAS (F.G.) COMPOSITION MOLES PER FUEL UNIT (AF)					b	
	FUEL CONSTITUENT	PER FUEL UNIT, LB	MOL. WT DIVI- SOR	MOLES FUEL CON- STIT- UENT	O <sub>2</sub> MUL- TI- PLI- ER	O <sub>2</sub> MOLES THEO- REQD	NO <sub>2</sub>	O <sub>2</sub>	N <sub>2</sub>	H <sub>2</sub> O	CO	
1	N <sub>2</sub> TO NO <sub>2</sub>		28	15.97	2	31.94	31.94					
2	C TO CO		12	0	.5	0					0	
3	CO TO CO <sub>2</sub>		28	0	.5	0						
4	C UNBURNED, LINE k		12	0								
5	H <sub>2</sub>		2	47.91	5	23.96				23.96		
6	S		32	0	1	0						
7	O <sub>2</sub> (DEDUCT)		32	0	1	0			0.00			
8	N <sub>2</sub>		28			0						
9	CO <sub>2</sub>		44	0		0						
10	H <sub>2</sub> O		18	0		0						
11	ASH											
12	SUM			63.88		55.90						
13	O <sub>2</sub> (THEO) REQD = O <sub>2</sub> , LINE 12					55.90						
14	O <sub>2</sub> (EXCESS) = $\frac{\text{T.A.} - 100}{100} \times \text{O}_2$ , LINE 12					0						
15	O <sub>2</sub> (TOTAL) SUPPLIED = LINES 13 + 14					55.90						
16	N <sub>2</sub> SUPPLIED = 3.73 X O <sub>2</sub> , LINE 15					208.37			208.37			
17	AIR (DRY) SUPPLIED = O <sub>2</sub> + N <sub>2</sub>					264.27						
18	H <sub>2</sub> O IN AIR = MOLES DRY AIR X $\frac{A}{B - A}$					1.96				1.96		
19	AIR (WET) SUPPLIED = LINES 17 + 18					266.23						
20	FLUE GAS CONSTITUENTS = LINES 1 TO 18, TOTAL						31.94	0	208.37	25.92	0	
21	*NOTE—FOR AIR AT 80 F AND 60% RELATIVE HUMIDITY, $\frac{A}{B - A} = 0.0212$ IS OFTEN USED AS STANDARD.											

\*NOTE: FLUE GAS ANALYSIS BY ORSAT, IF CO IS PRESENT IN FLUE GASES, A CARBON BALANCE IS USED TO DETERMINE DISTRIBUTION OF C, THUS:  
ALL C IN FUEL = C IN FLUE GAS CONSTITUENTS + C IN REFUSE. MOLES C IN FUEL = % C BY ANAL. + 12.  
C IN REFUSE = 12. MOLES C IN CO<sub>2</sub> = (MOLES C IN FUEL - MOLES C IN REFUSE) X % CO<sub>2</sub> BY ORSAT.

$$\frac{\% \text{N}_2}{\% \text{O}_2} = \frac{78.084}{20.948} = 3.7275$$

CONDITIONS—ASSIGNED OR OBSERVED  
AND MISCELLANEOUS

DATE January 4, 1996

FUEL NH<sub>3</sub> Ammonia Gas

SOURCE Vaporizer

FUEL UNIT 63.88 Moles, gaseous  
Fuels

FUEL ANAL. AS FIRED (AF), % BY WT OR VOL

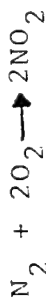
N<sub>2</sub> 25% by Volume

H<sub>2</sub> 75% by Volume

CO: NEGL. O <sub>2</sub> 21% CONEGL. N <sub>2</sub> 78%	c
TOTAL AIR (T.A.) ASSIGNED or by ORSAT 100%	d
LINES f, g, h FOR GASEOUS FUELS	e
WT, FUEL UNIT = Σ(MOLES EACH X MOL WT) LB	f
MOL WT OF FUEL = LINE	g
SP WT OF FUEL @ 80 F & 29.9" = $\frac{\text{LINE g}}{394}$ LB CU FT	h
FUEL HEAT VALUE, BTU/LB CU FT	i
COMBUSTIBLE IN REFUSE, % "C" 0%	j
CARBON UNBURNED, LB/100 LB FUEL % "C" 0.0	k
= % ASH IN FUEL X $\frac{100 - \% \text{"C"}}{100}$	
EXIT TEMP OF FLUE GAS, t <sub>2</sub>	l
DRY-BULB (AMBIENT) TEMP, t <sub>1</sub>	m
WET-BULB TEMP	n
REL HUMID. (PSYCHROMETRIC CHART) 100%	o
B° BAROMETRIC PRESSURE, psia 29.97	p
SAT. PRESS. H <sub>2</sub> O AT AMB TEMP, IN. 0.95	q
A° PRESS. H <sub>2</sub> O IN AIR, LINES (o X q), 0.95	r
TOTAL MOLES 266.23	s
WET FLUE GAS 240.31	
DRY FLUE GAS 240.31	
$\frac{0.95}{240.31 - 0.95} = 0.0074$	



# COMBUSTION CALCULATIONS—MOLAL BASIS



L	FUEL CONSTITUENT	FUEL, O <sub>2</sub> , AND AIR PER UNIT OF FUEL					FLUE GAS (F.G.) COMPOSITION MOLES PER FUEL UNIT (AF)				
		PER FUEL UNIT, LB	MOL WT DIVI- SOR	MOLES FUEL CON- STIT- UENT	O <sub>2</sub> MUL- TI- PLI- ER	O <sub>2</sub> MOLES THEO- RECD	NO <sub>2</sub>	O <sub>2</sub>	H <sub>2</sub>	H <sub>2</sub> O	CO
1	N <sub>2</sub> TO NO <sub>2</sub>	28		31.65	2	63.29	63.29				0
2	C TO CO	12		0	.5	0					
3	CO TO CO <sub>2</sub>	28		0	.5	0	0				
4	C UNBURNED, LINE k	12		0							
5	H <sub>2</sub>	2		0	.5	0					
6	S	32		0	1	0	0				
7	O <sub>2</sub> (DEDUCT)	32		0	1	0			0.00		
8	N <sub>2</sub>	28		0		0					
9	CO <sub>2</sub>	44		0		0	0				
10	H <sub>2</sub> O	18		0		0				0	
11	ASH			0		0					
12	SUM										
13	O <sub>2</sub> (THEO) REQD = O <sub>2</sub> , LINE 12					63.29					
14	O <sub>2</sub> (EXCESS) = $\frac{T.A. - 100}{100} \times O_2$ , LINE 12					0		0			
15	O <sub>2</sub> (TOTAL) SUPPLIED = LINES 13 + 14					63.29					
16	N <sub>2</sub> SUPPLIED = $(3.73 \times O_2)$ , LINE 15					204.26			204.26		
17	AIR (DRY) SUPPLIED = O <sub>2</sub> + N <sub>2</sub> (TOTAL)					299.20					
18	H <sub>2</sub> O IN AIR = MOLES DRY AIR $\times \frac{A}{B - A}$					2.21				2.21	
19	AIR (WET) SUPPLIED = LINES 17 + 18					301.41					
20	FLUE GAS CONSTITUENTS = LINES 1 TO 18, TOTAL						63.29	0	204.26	2.21	0
21	*NOTE—FOR AIR AT 80 F AND 60% RELATIVE HUMIDITY, $\frac{A}{B - A} = 0.0212$ IS OFTEN USED AS STANDARD. $\frac{0.95}{129.97 - 0.95} = 0.0074$										

\*NOTE: FLUE GAS ANALYSIS BY ORSAT, IF CO IS PRESENT IN FLUE GASES, A CARBON BALANCE IS USED TO DETERMINE DISTRIBUTION OF C, THUS:  
ALL C IN FUEL = C IN FLUE GAS CONSTITUENTS + C IN REFUSE. MOLES C IN FUEL = % C BY ANAL. + 12.  
ALL C IN FUEL = C IN FLUE GAS CONSTITUENTS + C IN REFUSE. MOLES C IN FUEL = (MOLES C IN REFUSE)  $\times$  % CO<sub>2</sub> BY ORSAT + % CO + CO BY ORSAT.

$$\frac{78.084}{20.948} = 3.727$$

---

## Calculations For: Theoretical Pound Moles per Hour Product Gas

---

$$\text{NO}_2: 31.94 \text{ #-mol/hr} + 63.29 \text{ #-mol/hr} = 95.23 \text{ #-mol/hr}$$

$$\text{N}_2: 208.37 \text{ #-mol/hr} + 204.26 \text{ #-mol/hr} = 412.63 \text{ #-mol/hr}$$

$$\text{H}_2\text{O}: 25.92 \text{ #-mol/hr} + 2.21 \text{ #-mol/hr} = 28.13 \text{ #-mol/hr}$$

From Sheet 1:

$$A_R: \frac{\text{lbs/hr} \times \text{mol. fract}}{\text{mol. wt. air}} = \frac{16480.19 \text{ lbs/hr} (0.00934)}{28.9644} = 5.31 \text{ #-mol/hr}$$

$$\text{Other: } \frac{\text{lbs/hr} \times \text{mol. fract}}{\text{mol. wt. air}} = \frac{16480.19 \text{ lbs/hr} (0.00034)}{28.9644} = 0.19 \text{ #-mol/hr}$$

$$\text{TOTAL} = 541.49 \text{ #-mol/hr}$$

$$\text{NO}_2 \text{ Percent by Volume} = \frac{95.23 \text{ #-mol/hr} (100)}{541.49 \text{ #-mol/hr}} = 17.59\%$$

$$\text{N}_2 \text{ Percent by Volume} = \frac{412.63}{541.49} = 76.20\%$$

$$\text{H}_2\text{O Percent by Volume} = \frac{28.13}{541.72} = 5.20\%$$

$$A_R \text{ Percent by Volume} = \frac{5.31}{541.49} = 0.98\%$$

$$\text{Other Percent by Volume} = \frac{0.19}{541.72} = 0.04\%$$

$$\text{TOTAL} = 100.01$$

## Calculations For: Product Gas Specific Heat at Constant Pressure

$$C_{PPRG} = \frac{W_{N_2} C_{PN_2} + W_{Ar} C_{PAR} + W_{NO_2} C_{PNO_2} + W_{H_2O} C_{PH_2O}}{W_{PR.G.}}$$

$$W_{N_2} = 412.63 \text{ \#moles/hr (28.013)} = 11559.00 \text{ \#/hr}$$

$$W_{Ar} = 5.31 \text{ \#moles/hr (39.948)} = 212.12 \text{ \#/hr}$$

$$W_{NO_2} = 95.23 \text{ \#moles/hr (46.005)} = 4381.06 \text{ \#/hr}$$

$$W_{H_2O} = 28.16 \text{ \#moles/hr (18.015)} = \underline{506.26 \text{ \#/hr}}$$

$$16658.94 \text{ \#/hr}$$

From Gas Table @ 1460° R

$$C_{PN_2} = \frac{\phi}{\ln T} = \frac{52.867}{\ln 1460} = 7.2558 \text{ }^B/\text{\#-mol } ^\circ F$$

$$C_{PAR} = \frac{\phi}{\ln T} = \frac{41.9242}{\ln 1460} = 5.7539 \text{ }^B/\text{\#-mol } ^\circ F$$

$$*C_{PNO_2} = \frac{\phi}{\ln T} = \frac{61.639}{\ln 1460} = 8.4597 \text{ }^B/\text{\#-mol } ^\circ F$$

$$C_{PH_2O} = \frac{\phi}{\ln T} = \frac{58.556}{\ln 1460} = 7.3503 \text{ }^B/\text{\#-mol } ^\circ F$$

$$C_{PPRG} = \frac{412.63 (7.2558) + 5.31 (5.7539) + 95.23 (7.2558) + 28.13 (7.3503)}{(541.49 - 0.19)}$$

$$= 7.2460 \text{ }^B/\text{\#-mol } ^\circ F$$

\*Assume specific heat of  $NO_2$  (MW = 46) is essentially the same as  $CO_2$  (MW = 44).

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## Calculations For: Dewpoint of Product Gas

---

$$P_V = \text{H}_2\text{O mol. fract.} \times P_{PG}$$

Where:  $P_V$  = vapor pressure of water.  
 $P_{PG}$  = product gas pressure.

$$P_V = 0.0520 (102 \text{ psig}) = 5.304 \text{ psig or } 20.0 \text{ psia}$$

$$\text{Saturation pressure of H}_2\text{O @ } 20 \text{ psia} = 227.96^\circ \text{ F}$$

$$\text{Dewpoint} = 227.96^\circ \text{ F}$$

### Mass Flow of Product Gas Constituents

$$\text{NO}_2 = (\# \text{-mol/hr}) (\#/\# \text{-mol}) = 95.23 (46.008) = 4381.34 \#/\text{hr}$$

$$\text{N}_2 = (\# \text{-mol/hr}) (\#/\# \text{-mol}) = 416.63 (28.016) = 11672.31 \#/\text{hr}$$

$$\text{H}_2\text{O} = (\# \text{-mol/hr}) (\#/\# \text{-mol}) = 28.13 (18.016) = 506.79 \#/\text{hr}$$

$$A_R = (\# \text{-mol/hr}) (\#/\# \text{-mol}) = 5.31 (39.95) = 16772.57 \#/\text{hr}$$

$$\text{Unaccounted} = 17644 - 16773 = 871 \#/\text{hr}$$

$$\text{Apparent Mol. Wt.} = \frac{17644 \#/\text{hr}}{541.49 \# \text{-mol/hr}} = 32.58 \#/\# \text{-mol}$$

$$C_p = \frac{7.2460 \text{ B}/\# \text{-mol } ^\circ \text{ F}}{32.58 \#/\# \text{-mol}} = 0.2224 \text{ B}/\# ^\circ \text{ F}$$

## Calculations For: Recoverable Heat

$$Q_{\text{REC}} = w C_p (T_{\text{IN}} - T_{\text{OUT}}) = 17644 (0.222) (800 - 400)/1000 \\ = 1570 \text{ MBH}$$

Assume feedwater entering boiler is 300°F and 65 psig

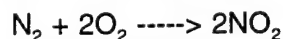
$$W_{\text{STM}} = \frac{1570000}{\Delta h} = \frac{1570000}{1183.1 - 282} = 1740 \text{ \#/hr} \\ @ 65 \text{ psig}$$

Volumetric Analysis - Product Gas/Bleaching Air:

Constituent	# Moles/Hr in Bleaching Air	# Moles/Hr in Pr. Gas Entg.	# Moles/Hr in New Pr. Gas	% By Volume
N <sub>2</sub>	74.93	416.63	491.56	76.57
A	0.90	5.31	6.21	0.97
O <sub>2</sub>	20.10	0*	20.10	3.13
NO <sub>2</sub>	0	95.23	95.23	14.83
H <sub>2</sub> O	0.71	28.13	28.84	4.49
			641.94	99.99

Bleaching Air: 2779 #DA/hr + 15.45 #H<sub>2</sub>O/hr = 2794.45 #/hr  
# moles DA/hr = 2779/28.96 = 95.96

\*Assume all available O<sub>2</sub> combines with available N<sub>2</sub>:



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## Calculations For: Absorption Column Spray Water and Tailgas

---

Spray Water Required =  $40.6 + 3.8 + 31.74 - 28.84 = 47.3 \text{ \# mol/hr}$

or  $\frac{47.3 \text{ \# mol/hr} (18.016 \text{ \#/#mol})}{8.33 \text{ \#/g} (60 \text{ m/hr})} = 1.70 \text{ gpm}$

or  $47.3 \text{ \# mol/hr} (18.016 \text{ \#/#mol}) = 855 \text{ \#/hr}$

Tail Gas	# Moles/Hr	Mol. Wt.	#/Hr
O <sub>2</sub>	20.1	32	643.2
N <sub>2</sub>	491.6	28.016	13772.7
NO	31.72	30.008	954.1
H <sub>2</sub> O	3.8	18.016	68.5
A <sub>R</sub>	6.21	39.948	248.1
Other	0.19	42.09	8.0
	553.62		15694.6

Apparent Mol. Wt. =  $\frac{15694.6}{553.62} = 28.349$

**Calculations For: 50 Tons/Day of 61% Acid by Volume  
(66.124 #-mol/hr HNO<sub>3</sub>) & Tailgas**

Constituent	# Moles Ent. Col	# Moles in Product	# Moles in Tailgas
N <sub>2</sub>	491.56	0	491.56
A <sub>R</sub>	6.21	0	6.21
O <sub>2</sub>	20.10	0	20.10
H <sub>2</sub> O	28.84	40.6	3.8
HNO <sub>3</sub>	0	63.48	0
NO	0	0	31.74
Reaction: 3NO <sub>2</sub> + H <sub>2</sub> O ----> 2 HNO <sub>3</sub> + NO			

Water in Reaction ----->  $\frac{95.23}{3} = 31.74 \text{ \# moles/hr}$

Water in Tailgas ----->  $\frac{P_v R_{TG}}{(P_m - P_v) R_v} = \frac{0.5959 (1544/30)}{(80 - 0.5959) (1544/18.016)} = 0.0045 \text{ \#/DTG}$   
(Saturated @ 85°F)

Water = 15400 (0.0045) = 69#/hr

Product -----> 63.48 # moles/hr (63.013 #/#mole) + (40.6 #mole/hr) (18.016 #/#mole)

= 4732 #/hr

% HNO<sub>3</sub> =  $\frac{63.48 (100)}{104.1} = 60.98 \text{ by Volume}$

% HNO<sub>3</sub> =  $\frac{63.48 (63.013) (100)}{4732} = 84.5 \text{ by Weight}$

---

## Calculations For: Product and Tailgas (By Molal Analysis)

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Absorption Column Mass Balance:

$$\begin{aligned}W_{IN} &= 491.56 (28.014) + 6.21 (39.948) + 95.23 (46.01) + 28.84 (18.016) + 855 + 20.1 (32) \\&= 20418 \text{ \#/hr}\end{aligned}$$

$$\begin{aligned}W_{OUT} &= 491.56 (28.014) + 6.21 (39.948) + 3.8 (18.016) + 31.74 (30.01) + 20.1 (32) + 4732 \\&= 20415 \text{ \#/hr}\end{aligned}$$

$$\text{Tailgas} = 20415 - 4732 = 15680 \text{ \#/hr}$$



## Calculations For: Tailgas (By Molal Analysis)

$$C_{PTG} = \frac{W_{N_2} C_{PN_2} + W_{AR} C_{PAR} + W_{NO} C_{PNO} + W_{H_2O} C_{PH_2O} + W_{O_2} C_{PO_2}}{W_{TG}}$$

$$W_{N_2} = 491.56 \text{ #-Mol/hr}$$

$$W_{AR} = 6.21 \text{ #-Mol/hr}$$

$$W_{NO} = 31.74 \text{ #-Mol/hr}$$

$$W_{H_2O} = 3.8 \text{ #-Mol/hr}$$

$$W_{O_2} = 20.1/553.41 \text{ #-Mol/hr}$$

Calculate  $C_p$  @ 350°F (810°R) - Value of  $\phi$  from gas tables

$$C_{pO_2} = \frac{\phi}{\ln T} = \frac{51.911}{\ln 810} = 7.751 \text{ B/ #-Mol}^\circ\text{F}$$

$$C_{pN_2} = \frac{\phi}{\ln T} = \frac{48.61}{\ln 810} = 7.2584 \text{ B/ #-Mol}^\circ\text{F}$$

$$C_{PAR} = \frac{\phi}{\ln T} = \frac{38.9994}{\ln 810} = 5.8234 \text{ B/ #-Mol}^\circ\text{F}$$

$$*C_{PNO} = \frac{\phi}{\ln T} = \frac{50.146}{\ln 810} = 7.4878 \text{ B/ #-Mol}^\circ\text{F}$$

$$C_{PH_2O} = \frac{\phi}{\ln T} = \frac{48.419}{\ln 810} = 7.2299 \text{ B/ #-Mol}^\circ\text{F}$$

$$C_{PTG} = \frac{491.56 (7.2584) + 6.21 (5.8234) + 31.74 (7.4878) + 3.8 (7.2299) + 20.1 (7.7513)}{553.41}$$

$$7.2732 \text{ B/ #-Mol}^\circ\text{F}$$

or

$$\frac{7.2732 \text{ B/ #-Mol}^\circ\text{F} (553.41 \text{ #-Mol/hr})}{15680 \text{ #-Mol/hr}} = 0.257 \text{ B/ #-Mol}^\circ\text{F}$$

## Cost Data

"Means Mechanical Cost Data", 19th Annual Edition, 1996 was used for unit price data for the majority of line items entered on estimating forms. Pipe fittings and accessories were entered as  $\pm 80$  percent of run-of-pipe cost. Major equipment pricing, where not included in "Means", was developed from published cost of similar devices tempered by engineering judgement.

ECO costs were developed for a single process line, including equipment shown on the Process Flow Diagrams. Provisions for "Crossover" to permit any one of the five air compressors, for instance, is not included, nor is the provision to interconnect any other new device in one process line with its companion device in an adjacent process line. Additional expenditures to implement similar changes on a second line will not produce additional savings at the present production rate.

Cost estimate analysis sheets for each ECO are included in this section, followed by Life Cycle Analysis Summary sheets from the LCIDD computer program.

Cost analysis rough worksheets are presented in Appendix.

COST ESTIMATE ANALYSIS							DATE PREPARED: 11/14/95		
							ESTIMATOR: PDL		
PROJECT: HOLSTON AAP AREA B NITRIC ACID					LOCATION: KINGSPORT, TENNESSEE				
TASK DESCRIPTION	QUANTITY		LABOR		EQUIPMENT		MATERIAL		TOTAL
	NO OF UNITS	UNIT MEAS	UNIT PRICE	COST	UNIT PRICE	COST	UNIT PRICE	COST	
ECO NO. 1									
STEAM PIPING:									
6" ø Sch.40 Undrgr.	250	LF	16.55	4138	1.28	320	31.00	7750	\$12,208.00
3" ø Sch. 80 Undrgr.	250	LF	17.65	4413	1.28	320	19.50	4875	9608.00
4" ø Sch. 40	150	LF	11.70	1755	1.40	210	10.60	1590	3555.00
2" ø Sch. 80	150	LF	7.75	1163	.86	129	5.50	837	2129.00
Pipe Insul.	300	LF		2000				1000	3000.00
Turbin Mod. Cost		LS		10000				10000	20000.00
15000#/Hr. Stm. Surf. Cndns.	1	EA		10000		2500		30000	42500.00
Cond. Pump	1	EA		300				1500	1800.00
8" Condnsr Wtr. Piping	300	LF	23	6900	1.81	543	31.00	9300	16743.00
Pipe Ftgs & Misc.	1	LOT		10000				25000	35000.00
TOTAL				50669		4022		91852	\$146,543.00

**COST ESTIMATE ANALYSIS**

DATE PREPARED: 11/14/95

ESTIMATOR: PDL

**PROJECT:** HOLSTON AAP AREA B NITRIC ACID**LOCATION:** KINGSPORT, TENNESSEE

TASK DESCRIPTION	QUANTITY		LABOR		EQUIPMENT		MATERIAL		TOTAL
	NO OF UNITS	UNIT MEAS	UNIT PRICE	COST	UNIT PRICE	COST	UNIT PRICE	COST	
ECO NO. 2									
STEAM PIPING:									
8" ø Sch.40 Undrgr.	250	LF	17.40	4350	1.28	320	33.50	8375	\$13,045.00
3" ø Sch. 80 Undrgr.	250	LF	17.65	4413	1.28	320	19.50	4875	9608.00
8" ø Sch. 40	150	LF	23.00	3450	1.81	272	31.00	4650	8372.00
2" ø Sch. 80	150	LF	7.75	1163	.86	129	5.50	837	2129.00
Pipe Insul.	1	LOT		2500				1200	3700.00
DOWTHERM PIPE:									
2 1/2" ø Sch. 40	200	LF	9.20	1840	1.12	224	6.40	1280	3344.00
Pipe Insul.	1	LOT		2000				1000	3000.00
Hi Temp Pump (406 GPM)	1	EA		300				3438	3738.00
65 GPM Pump	1	EA		216				1375	1591.00
N <sub>2</sub> Blnkt. Syst.	1	EA		250				1000	1250.00
Unfired Blr. Vessel	1	EA		5000		2500		75000	82500.00
Misc. Acces. & Fittings	1	LOT		20000				40000	60000.00
<b>TOTAL</b>				<b>45482</b>		<b>3765</b>		<b>143030</b>	<b>\$192,277.00</b>

COST ESTIMATE ANALYSIS							DATE PREPARED: 11/14/95		
							ESTIMATOR: PDL		
PROJECT: HOLSTON AAP AREA B NITRIC ACID					LOCATION: KINGSPORT, TENNESSEE				
TASK DESCRIPTION	QUANTITY		LABOR		EQUIPMENT		MATERIAL		TOTAL
	NO OF UNITS	UNIT MEAS	UNIT PRICE	COST	UNIT PRICE	COST	UNIT PRICE	COST	
ECO NO. 3									
FIBERGLASS COOLING TOWER									
600 GPM Ind. Dr.	1	EA		1500		1000		12000	\$14,500.00
Pumps & Piping	1	LOT		3500				7200	10700.00
Elect		LS		3000				5000	8000.00
Sitework/Pads		LS		5000				1000	6000.00
TOTAL				13000		1000		25200	39,200.00

COST ESTIMATE ANALYSIS					DATE PREPARED: 11/14/95		
					ESTIMATOR: PDL		
PROJECT: HOLSTON AAP AREA B NITRIC ACID				LOCATION: KINGSPORT, TENNESSEE			
TASK DESCRIPTION	QUANTITY		LABOR		MATERIAL		TOTAL
	NO OF UNITS	UNIT MEAS	UNIT PRICE	COST	UNIT PRICE	COST	
Insulation ECO NO. 4							
1" CALCIUM SILICATE:							
18" ø Air Preheater	12	LF	5.40	64.80	9.35	112.20	\$ 177.00
18" ø Tailgas Heater	25	LF	5.40	135.00	9.35	233.75	368.75
8" ø Tailgas Pipe to Turbine	120	LF	3.84	460.80	4.26	511.20	972.00
0.010 S.S. JACKET:							
18" ø Air Preheater	60	SF	4.03	241.80	.93	55.80	297.60
18" ø Tailgas Heater	125	SF	4.03	503.75	.93	116.25	620.00
8" ø Tailgas Pipe to Turbine	315	SF	4.03	1,269.45	.93	292.95	1,562.40
18" ø Flange Sets (Insulation)	10	SF	13.45	134.50	2.71	27.10	\$161.60
18" ø Flange Sets (Jacket)	10	SF	4.03	40.30	.93	9.30	\$49.60
Subtotal			\$2,850.40			\$1,358.55	\$ 4,208.95
15% Conting							631.35
TOTAL Construction Use							\$ 4,850.00

COST ESTIMATE ANALYSIS					DATE PREPARED: 11/14/95		
					ESTIMATOR: PDL		
PROJECT: HOLSTON AAP AREA B NITRIC ACID				LOCATION: KINGSPORT, TENNESSEE			
TASK DESCRIPTION ECO NO. 5	QUANTITY		LABOR		MATERIAL		TOTAL
	NO OF UNITS	UNIT MEAS	UNIT PRICE	COST	UNIT PRICE	COST	
18" Semicircular							
Plate Heat Exchanger 14' Long	1	EA		100.00		5,000.00	\$ 5,100.00
Clayton Whsg. Waste							
Heat Steam Generator	1	EA		2,000.00		5,000.00	7,000.00
Condensate Cooler	1	EA		100.00		500.00	600.00
Cond. Rcvr/Pump	1	EA		300.00		1,500.00	1,800.00
1-1/4" ø Insulated							
Pipe & Fittings	1	LOT		7,500.00		5,000.00	\$12,500.00
TOTAL				10,000.00		17,000.00	\$ 27,000.00

COST ESTIMATE ANALYSIS							DATE PREPARED: 11/14/95		
							ESTIMATOR: PDL		
PROJECT: HOLSTON AAP AREA B NITRIC ACID				LOCATION: KINGSPORT, TENNESSEE					
TASK DESCRIPTION	QUANTITY		LABOR		EQUIPMENT		MATIERIAL		TOTAL
	NO OF UNITS	UNIT MEAS	UNIT PRICE	COST	UNIT PRICE	COST	UNIT PRICE	COST	
ECO NO. 7									
Makeup & Fowtr. Pipe - 1" ø	500	LF	4.65	4138	.57	285	2.89	1445.00	\$4,055.00
Steam Pipe - 1-1/2" ø	150	LF	5.70	4413	.69	104	3.96	594.00	1,553.00
400 Series St. Stl. Econom.	1	EA		1755		500		185500.00	188,000.00
Waste Ht. Blr. System	1	EA		1,500		150		68600.00	70,250.00
Fdwtr Pump-46 PM/225 TDH	1	EA	72.50	1163			500	500.00	573.00
Temperature Controls	1	SET	150.00	2000			850	850.00	1,000.00
6"ø A3126RTP321 Pipe	40	LF	20.00	10000	1.50	60	60	2400.00	3,260.00
Heater Insulation		LS		300				1360.00	4,210.00
Steam Pipe Insul	150	LF	2.49	6900			2.23	335.00	709.00
Fdwtr Pipe Insul	150	LF	2.42	10000			2.16	324.00	687.00
Surge Tank - 100 Gag	1	EA		25				100.00	\$125.00
Pipe Fittings & Accos.	1	LOT		2000				5500.00	\$7,500.00
Subtotal				13,315			1,099	267508.00	\$281,922.00
**Cost W.O. St. Stl. Sect.									\$93,922.00



LIFE CYCLE COST ANALYSIS SUMMARY                      STUDY: 95094  
ENERGY CONSERVATION INVESTMENT PROGRAM (ECIP)                      LCCID 1.080  
INSTALLATION & LOCATION: HOLSTON ARMY AREGION NOS. 4 CENSUS: 3  
PROJECT NO. & TITLE: 95094 AREA B NITRIC ACID PRODUCTION FACILITY  
FISCAL YEAR 1996                      DISCRETE PORTION NAME: ECO #1 STM. TURB.DRIVE @ AIR COMPR.  
ANALYSIS DATE: 12-21-95                      ECONOMIC LIFE 20 YEARS PREPARED BY: LITTLE

1. INVESTMENT

A. CONSTRUCTION COST	\$	146543.	
B. SIOH	\$	14661.	
C. DESIGN COST	\$	15993.	
D. TOTAL COST (1A+1B+1C)	\$	177197.	
E. SALVAGE VALUE OF EXISTING EQUIPMENT	\$	0.	
F. PUBLIC UTILITY COMPANY REBATE	\$	0.	
G. TOTAL INVESTMENT (1D - 1E - 1F)	\$	177197.	

2. ENERGY SAVINGS (+) / COST (-)

DATE OF NISTIR 85-3273-X USED FOR DISCOUNT FACTORS OCT 1993

FUEL	UNIT COST \$/MBTU(1)	SAVINGS MBTU/YR(2)	ANNUAL \$ SAVINGS(3)	DISCOUNT FACTOR(4)	DISCOUNTED SAVINGS(5)
A. ELECT	\$ 10.25	2325.	\$ 23831.	15.61	\$ 372001.
B. DIST	\$ .00	0.	\$ 0.	17.56	\$ 0.
C. RESID	\$ .00	0.	\$ 0.	19.97	\$ 0.
D. NAT G	\$ .00	0.	\$ 0.	20.96	\$ 0.
E. COAL	\$ .00	0.	\$ 0.	17.58	\$ 0.
F. LPG	\$ .00	0.	\$ 0.	16.12	\$ 0.
L. OTHER	\$ 3.90	-10538.	\$ -41097.	14.74	\$ -605775.
M. DEMAND SAVINGS			\$ 13050.	14.74	\$ 192357.
N. TOTAL		-8213.	\$ -4216.		\$ -41417.

3. NON ENERGY SAVINGS(+) / COST(-)

A. ANNUAL RECURRING (+/-)	\$	0.
(1) DISCOUNT FACTOR (TABLE A)	14.74	
(2) DISCOUNTED SAVING/COST (3A X 3A1)	\$	0.

B. NON RECURRING SAVINGS(+) / COSTS(-)

ITEM	SAVINGS(+) COST(-) (1)	YR OC (2)	DISCNT FACTR (3)	DISCOUNTED SAVINGS(+)/ COST(-)(4)
------	------------------------------	-----------------	------------------------	---

d. TOTAL	\$	0.		0.
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C. TOTAL NON ENERGY DISCOUNTED SAVINGS(+)/COST(-)(3A2+3Bd4)\$ 0.

4. FIRST YEAR DOLLAR SAVINGS  $2N3+3A+(3Bd1/(YRS \text{ ECONOMIC LIFE}))$ \$ -4216.

5. SIMPLE PAYBACK PERIOD (1G/4) -42.03 YEARS

6. TOTAL NET DISCOUNTED SAVINGS (2N5+3C) \$ -41417.

7. SAVINGS TO INVESTMENT RATIO (SIR)=(6 / 1G)= -.23  
(IF < 1 PROJECT DOES NOT QUALIFY)

\*\*\*\* Project does not qualify for ECIP funding; 4,5,6 for information only.

8. ADJUSTED INTERNAL RATE OF RETURN (AIRR): N/A

LIFE CYCLE COST ANALYSIS SUMMARY

STUDY: 95094

LCCID 1.080

ENERGY CONSERVATION INVESTMENT PROGRAM (ECIP)

INSTALLATION & LOCATION: HOLSTON ARMY AREGION NOS. 4 CENSUS: 3

PROJECT NO. & TITLE: 95094 AREA B NITRIC ACID PRODUCTION FACILITY

FISCAL YEAR 1996 DISCRETE PORTION NAME: ECO #2 REJCTD HT CNVRTD TO 100# STM

ANALYSIS DATE: 12-21-95 ECONOMIC LIFE 20 YEARS PREPARED BY: LITTLE

1. INVESTMENT

A. CONSTRUCTION COST	\$	192275.	
B. SIOH	\$	10576.	
C. DESIGN COST	\$	11537.	
D. TOTAL COST (1A+1B+1C)	\$	214388.	
E. SALVAGE VALUE OF EXISTING EQUIPMENT	\$	0.	
F. PUBLIC UTILITY COMPANY REBATE	\$	0.	
G. TOTAL INVESTMENT (1D - 1E - 1F)	\$		214388.

2. ENERGY SAVINGS (+) / COST (-)

DATE OF NISTIR 85-3273-X USED FOR DISCOUNT FACTORS OCT 1993

FUEL	UNIT COST \$/MBTU(1)	SAVINGS MBTU/YR(2)	ANNUAL \$ SAVINGS(3)	DISCOUNT FACTOR(4)	DISCOUNTED SAVINGS(5)
A. ELECT	\$ 10.25	-885.	\$ -9071.	15.61	\$ -141602.
B. DIST	\$ .00	0.	\$ 0.	17.56	\$ 0.
C. RESID	\$ .00	0.	\$ 0.	19.97	\$ 0.
D. NAT G	\$ .00	0.	\$ 0.	20.96	\$ 0.
E. COAL	\$ .00	0.	\$ 0.	17.58	\$ 0.
F. LPG	\$ .00	0.	\$ 0.	16.12	\$ 0.
L. OTHER	\$ 3.90	3445.	\$ 13436.	14.74	\$ 198039.
M. DEMAND SAVINGS			\$ -1855.	14.74	\$ -27343.
N. TOTAL		2560.	\$ 2509.		\$ 29094.

3. NON ENERGY SAVINGS(+) / COST(-)

A. ANNUAL RECURRING (+/-)		\$ -1080.
(1) DISCOUNT FACTOR (TABLE A)	14.74	
(2) DISCOUNTED SAVING/COST (3A X 3A1)		\$ -15919.

B. NON RECURRING SAVINGS(+) / COSTS(-)

ITEM	SAVINGS(+) COST(-) (1)	YR OC (2)	DISCNT FACTR (3)	DISCOUNTED SAVINGS(+)/ COST(-)(4)
d. TOTAL	\$ 0.			0.

C. TOTAL NON ENERGY DISCOUNTED SAVINGS(+)/COST(-)(3A2+3Bd4)\$ -15919.

4. FIRST YEAR DOLLAR SAVINGS  $2N3+3A+(3Bd1/(YRS\ ECONOMIC\ LIFE))$ \$ 1429.

5. SIMPLE PAYBACK PERIOD (1G/4) 150.00 YEARS

6. TOTAL NET DISCOUNTED SAVINGS (2N5+3C) \$ 13175.

7. SAVINGS TO INVESTMENT RATIO (SIR)=(6 / 1G)= .06  
(IF < 1 PROJECT DOES NOT QUALIFY)

8. ADJUSTED INTERNAL RATE OF RETURN (AIRR): -10.32 %

LIFE CYCLE COST ANALYSIS SUMMARY

STUDY: 95094

ENERGY CONSERVATION INVESTMENT PROGRAM (ECIP)      LCCID 1.080

INSTALLATION & LOCATION: HOLSTON ARMY AREGION NOS. 4 CENSUS: 3

PROJECT NO. & TITLE: 95094 AREA B NITRIC ACID PRODUCTION FACILITY

FISCAL YEAR 1996      DISCRETE PORTION NAME: ECO #3 REDUCED WTR CONSUMP W/ CLNG TWR

ANALYSIS DATE: 12-21-95 ECONOMIC LIFE 20 YEARS PREPARED BY: LITTLE

1. INVESTMENT

A. CONSTRUCTION COST	\$	39200.	
B. SIOH	\$	2156.	
C. DESIGN COST	\$	2352.	
D. TOTAL COST (1A+1B+1C)	\$	43708.	
E. SALVAGE VALUE OF EXISTING EQUIPMENT	\$	0.	
F. PUBLIC UTILITY COMPANY REBATE	\$	0.	
G. TOTAL INVESTMENT (1D - 1E - 1F)	\$	43708.	

2. ENERGY SAVINGS (+) / COST (-)

DATE OF NISTIR 85-3273-X USED FOR DISCOUNT FACTORS OCT 1993

FUEL	UNIT COST \$/MBTU(1)	SAVINGS MBTU/YR(2)	ANNUAL \$ SAVINGS(3)	DISCOUNT FACTOR(4)	DISCOUNTED SAVINGS(5)
A. ELECT	\$ 10.25	-65.	\$ -666.	15.61	\$ -10400.
B. DIST	\$ .00	0.	\$ 0.	17.56	\$ 0.
C. RESID	\$ .00	0.	\$ 0.	19.97	\$ 0.
D. NAT G	\$ .00	0.	\$ 0.	20.96	\$ 0.
E. COAL	\$ .00	0.	\$ 0.	17.58	\$ 0.
F. LPG	\$ .00	0.	\$ 0.	16.12	\$ 0.
M. DEMAND SAVINGS			\$ 0.	14.74	\$ 0.
N. TOTAL		-65.	\$ -666.		\$ -10400.

3. NON ENERGY SAVINGS(+) / COST(-)

A. ANNUAL RECURRING (+/-)		\$	5524.
(1) DISCOUNT FACTOR (TABLE A)	14.74		
(2) DISCOUNTED SAVING/COST (3A X 3A1)		\$	81424.

B. NON RECURRING SAVINGS(+) / COSTS(-)

ITEM	SAVINGS(+) COST(-) (1)	YR OC (2)	DISCNT FACTR (3)	DISCOUNTED SAVINGS(+)/ COST(-)(4)
d. TOTAL	\$ 0.			0.

C. TOTAL NON ENERGY DISCOUNTED SAVINGS(+)/COST(-)(3A2+3Bd4)\$ 81424.

4. FIRST YEAR DOLLAR SAVINGS  $2N3+3A+(3Bd1/(YRS \text{ ECONOMIC LIFE}))$ \$ 4858.

5. SIMPLE PAYBACK PERIOD (1G/4) 9.00 YEARS

6. TOTAL NET DISCOUNTED SAVINGS (2N5+3C) \$ 71024.

7. SAVINGS TO INVESTMENT RATIO (SIR)=(6 / 1G)= 1.62  
(IF < 1 PROJECT DOES NOT QUALIFY)

\*\*\*\* Project does not qualify for ECIP funding; 4,5,6 for information only.

8. ADJUSTED INTERNAL RATE OF RETURN (AIRR): N/A

LIFE CYCLE COST ANALYSIS SUMMARY

STUDY: 95094  
LCCID 1.080

ENERGY CONSERVATION INVESTMENT PROGRAM (ECIP)

INSTALLATION & LOCATION: HOLSTON ARMY AREGION NOS. 4 CENSUS: 3

PROJECT NO. & TITLE: 95094 AREA B NITRIC ACID PRODUCTION FACILITY

FISCAL YEAR 1996 DISCRETE PORTION NAME: ECO #4 INSULATE HEAT EXCHANGERS

ANALYSIS DATE: 12-21-95 ECONOMIC LIFE 20 YEARS PREPARED BY: LITTLE

1. INVESTMENT

A. CONSTRUCTION COST	\$	4850.	
B. SIOH	\$	267.	
C. DESIGN COST	\$	291.	
D. TOTAL COST (1A+1B+1C)	\$	5408.	
E. SALVAGE VALUE OF EXISTING EQUIPMENT	\$	0.	
F. PUBLIC UTILITY COMPANY REBATE	\$	0.	
G. TOTAL INVESTMENT (1D - 1E - 1F)	\$		5408.

2. ENERGY SAVINGS (+) / COST (-)

DATE OF NISTIR 85-3273-X USED FOR DISCOUNT FACTORS OCT 1993

FUEL	UNIT COST \$/MBTU(1)	SAVINGS MBTU/YR(2)	ANNUAL \$ SAVINGS(3)	DISCOUNT FACTOR(4)	DISCOUNTED SAVINGS(5)
A. ELECT	\$ 10.25	460.	\$ 4718.	15.61	\$ 73656.
B. DIST	\$ .00	0.	\$ 0.	17.56	\$ 0.
C. RESID	\$ .00	0.	\$ 0.	19.97	\$ 0.
D. NAT G	\$ .00	0.	\$ 0.	20.96	\$ 0.
E. COAL	\$ .00	0.	\$ 0.	17.58	\$ 0.
F. LPG	\$ .00	0.	\$ 0.	16.12	\$ 0.
M. DEMAND SAVINGS			\$ 2585.	14.74	\$ 38103.
N. TOTAL		460.	\$ 7303.		\$ 111758.

3. NON ENERGY SAVINGS(+) / COST(-)

A. ANNUAL RECURRING (+/-)		\$	0.
(1) DISCOUNT FACTOR (TABLE A)		14.74	
(2) DISCOUNTED SAVING/COST (3A X 3A1)		\$	0.

B. NON RECURRING SAVINGS(+) / COSTS(-)

ITEM	SAVINGS(+) COST(-) (1)	YR OC (2)	DISCNT FACTR (3)	DISCOUNTED SAVINGS(+)/ COST(-)(4)
d. TOTAL	\$ 0.			0.

C. TOTAL NON ENERGY DISCOUNTED SAVINGS(+)/COST(-)(3A2+3Bd4)\$ 0.

4. FIRST YEAR DOLLAR SAVINGS  $2N3+3A+(3Bd1/(YRS \text{ ECONOMIC LIFE}))$ \$ 7303.

5. SIMPLE PAYBACK PERIOD (1G/4) .74 YEARS

6. TOTAL NET DISCOUNTED SAVINGS (2N5+3C) \$ 111758.

7. SAVINGS TO INVESTMENT RATIO (SIR)=(6 / 1G)= 20.67  
(IF < 1 PROJECT DOES NOT QUALIFY)

8. ADJUSTED INTERNAL RATE OF RETURN (AIRR): 19.96 %

LIFE CYCLE COST ANALYSIS SUMMARY

STUDY: 95094  
LCCID 1.080

ENERGY CONSERVATION INVESTMENT PROGRAM (ECIP)

INSTALLATION & LOCATION: HOLSTON ARMY AREGION NOS. 4 CENSUS: 3

PROJECT NO. & TITLE: 95094 AREA B NITRIC ACID PRODUCTION FACILITY

FISCAL YEAR 1996 DISCRETE PORTION NAME: ECO #5 INSUL HX S W/ NEW 30# STM SYST

ANALYSIS DATE: 12-21-95 ECONOMIC LIFE 20 YEARS PREPARED BY: LITTLE

1. INVESTMENT

A. CONSTRUCTION COST	\$	31850.	
B. SIOH	\$	1752.	
C. DESIGN COST	\$	1911.	
D. TOTAL COST (1A+1B+1C)	\$	35513.	
E. SALVAGE VALUE OF EXISTING EQUIPMENT	\$	0.	
F. PUBLIC UTILITY COMPANY REBATE	\$	0.	
G. TOTAL INVESTMENT (1D - 1E - 1F)	\$		35513.

2. ENERGY SAVINGS (+) / COST (-)

DATE OF NISTIR 85-3273-X USED FOR DISCOUNT FACTORS OCT 1993

FUEL	UNIT COST \$/MBTU(1)	SAVINGS MBTU/YR(2)	ANNUAL \$ SAVINGS(3)	DISCOUNT FACTOR(4)	DISCOUNTED SAVINGS(5)
A. ELECT	\$ 10.25	460.	\$ 4718.	15.61	\$ 73656.
B. DIST	\$ .00	0.	\$ 0.	17.56	\$ 0.
C. RESID	\$ .00	0.	\$ 0.	19.97	\$ 0.
D. NAT G	\$ .00	0.	\$ 0.	20.96	\$ 0.
E. COAL	\$ .00	0.	\$ 0.	17.58	\$ 0.
F. LPG	\$ .00	0.	\$ 0.	16.12	\$ 0.
L. OTHER	\$ 3.90	664.	\$ 2589.	14.74	\$ 38159.
M. DEMAND SAVINGS			\$ 2585.	14.74	\$ 38103.
N. TOTAL		1124.	\$ 9892.		\$ 149918.

3. NON ENERGY SAVINGS(+) / COST(-)

A. ANNUAL RECURRING (+/-)		\$ -132.
(1) DISCOUNT FACTOR (TABLE A)	14.74	
(2) DISCOUNTED SAVING/COST (3A X 3A1)		\$ -1946.

B. NON RECURRING SAVINGS(+) / COSTS(-)

ITEM	SAVINGS(+) COST(-) (1)	YR OC (2)	DISCNT FACTR (3)	DISCOUNTED SAVINGS(+)/ COST(-)(4)
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d. TOTAL	\$ 0.			0.
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c. TOTAL NON ENERGY DISCOUNTED SAVINGS(+) / COST(-) (3A2+3Bd4)	\$ -1946.
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4. FIRST YEAR DOLLAR SAVINGS $2N3+3A+(3Bd1/(YRS\ ECONOMIC\ LIFE))$	\$ 9760.
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5. SIMPLE PAYBACK PERIOD (1G/4)	3.64 YEARS
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6. TOTAL NET DISCOUNTED SAVINGS (2N5+3C)	\$ 147972.
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7. SAVINGS TO INVESTMENT RATIO (SIR)=(6 / 1G)=	4.17
(IF < 1 PROJECT DOES NOT QUALIFY)	

8. ADJUSTED INTERNAL RATE OF RETURN (AIRR):	10.73 %
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LIFE CYCLE COST ANALYSIS SUMMARY

STUDY: 95094

LCCID 1.080

ENERGY CONSERVATION INVESTMENT PROGRAM (ECIP)

INSTALLATION & LOCATION: HOLSTON ARMY AREGION NOS. 4 CENSUS: 3

PROJECT NO. & TITLE: 95094 AREA B NITRIC ACID PRODUCTION FACILITY

FISCAL YEAR 1996 DISCRETE PORTION NAME: ECO #7 RECOVERED STM INJECT @ TLGS TURB

ANALYSIS DATE: 12-22-95 ECONOMIC LIFE 20 YEARS PREPARED BY: LITTLE

1. INVESTMENT

A. CONSTRUCTION COST	\$	281920.	
B. SIOH	\$	4125.	
C. DESIGN COST	\$	4500.	
D. TOTAL COST (1A+1B+1C)	\$	290545.	
E. SALVAGE VALUE OF EXISTING EQUIPMENT	\$	0.	
F. PUBLIC UTILITY COMPANY REBATE	\$	0.	
G. TOTAL INVESTMENT (1D - 1E - 1F)	\$	290545.	

2. ENERGY SAVINGS (+) / COST (-)

DATE OF NISTIR 85-3273-X USED FOR DISCOUNT FACTORS OCT 1993

FUEL	UNIT COST \$/MBTU(1)	SAVINGS MBTU/YR(2)	ANNUAL \$ SAVINGS(3)	DISCOUNT FACTOR(4)	DISCOUNTED SAVINGS(5)
A. ELECT	\$ 10.25	683.	\$ 7002.	15.61	\$ 109304.
B. DIST	\$ .00	0.	\$ 0.	17.56	\$ 0.
C. RESID	\$ .00	0.	\$ 0.	19.97	\$ 0.
D. NAT G	\$ .00	0.	\$ 0.	20.96	\$ 0.
E. COAL	\$ .00	0.	\$ 0.	17.58	\$ 0.
F. LPG	\$ .00	0.	\$ 0.	16.12	\$ 0.
M. DEMAND SAVINGS			\$ 3835.	14.74	\$ 56528.
N. TOTAL		683.	\$ 10837.		\$ 165832.

3. NON ENERGY SAVINGS(+) / COST(-)

A. ANNUAL RECURRING (+/-)		\$ -412.
(1) DISCOUNT FACTOR (TABLE A)	14.74	
(2) DISCOUNTED SAVING/COST (3A X 3A1)		\$ -6073.

B. NON RECURRING SAVINGS(+) / COSTS(-)

ITEM	SAVINGS(+) COST(-) (1)	YR OC (2)	DISCNT FACTR (3)	DISCOUNTED SAVINGS(+)/ COST(-)(4)
d. TOTAL	\$ 0.			0.

C. TOTAL NON ENERGY DISCOUNTED SAVINGS(+)/COST(-)(3A2+3Bd4)\$ -6073.

4. FIRST YEAR DOLLAR SAVINGS  $2N3+3A+(3Bd1/(YRS\ ECONOMIC\ LIFE))$ \$ 10425.

5. SIMPLE PAYBACK PERIOD (1G/4) 27.87 YEARS

6. TOTAL NET DISCOUNTED SAVINGS (2N3+3C) \$ 159759.

7. SAVINGS TO INVESTMENT RATIO (SIR)=(6 / 1G)= .55  
(IF < 1 PROJECT DOES NOT QUALIFY)

8. ADJUSTED INTERNAL RATE OF RETURN (AIRR): .06 %

LIFE CYCLE COST ANALYSIS SUMMARY

STUDY: 95094  
LCCID 1.080

ENERGY CONSERVATION INVESTMENT PROGRAM (ECIP)

INSTALLATION & LOCATION: HOLSTON ARMY AREGION NOS. 4 CENSUS: 3

PROJECT NO. & TITLE: 95094 AREA B NITRIC ACID PRODUCTION FACILITY

FISCAL YEAR 1996 DISCRETE PORTION NAME: ECO #74 RECOVERED STM INJECT @ TLGS TURB

ANALYSIS DATE: 12-22-95 ECONOMIC LIFE 20 YEARS PREPARED BY: LITTLE

1. INVESTMENT

A. CONSTRUCTION COST	\$	93920.	
B. SIOH	\$	4125.	
C. DESIGN COST	\$	4500.	
D. TOTAL COST (1A+1B+1C)	\$	102545.	
E. SALVAGE VALUE OF EXISTING EQUIPMENT	\$	0.	
F. PUBLIC UTILITY COMPANY REBATE	\$	0.	
G. TOTAL INVESTMENT (1D - 1E - 1F)	\$		102545.

2. ENERGY SAVINGS (+) / COST (-)

DATE OF NISTIR 85-3273-X USED FOR DISCOUNT FACTORS OCT 1993

FUEL	UNIT COST \$/MBTU(1)	SAVINGS MBTU/YR(2)	ANNUAL \$ SAVINGS(3)	DISCOUNT FACTOR(4)	DISCOUNTED SAVINGS(5)
A. ELECT	\$ 10.25	670.	\$ 6868.	15.61	\$ 107202.
B. DIST	\$ .00	0.	\$ 0.	17.56	\$ 0.
C. RESID	\$ .00	0.	\$ 0.	19.97	\$ 0.
D. NAT G	\$ .00	0.	\$ 0.	20.96	\$ 0.
E. COAL	\$ .00	0.	\$ 0.	17.58	\$ 0.
F. LPG	\$ .00	0.	\$ 0.	16.12	\$ 0.
M. DEMAND SAVINGS			\$ 3835.	14.74	\$ 56528.
N. TOTAL		670.	\$ 10703.		\$ 163730.

3. NON ENERGY SAVINGS(+) / COST(-)

A. ANNUAL RECURRING (+/-)		\$	-412.
(1) DISCOUNT FACTOR (TABLE A)	14.74		
(2) DISCOUNTED SAVING/COST (3A X 3A1)		\$	-6073.

B. NON RECURRING SAVINGS(+) / COSTS(-)

ITEM	SAVINGS(+) / COST(-) (1)	YR OC (2)	DISCNT FACTR (3)	DISCOUNTED SAVINGS(+)/ COST(-)(4)
d. TOTAL	\$ 0.			0.

C. TOTAL NON ENERGY DISCOUNTED SAVINGS(+) / COSTS(-) (3A2+3Bd4) \$ -6073.

4. FIRST YEAR DOLLAR SAVINGS ((3A2+3Bd4) / (ECONOMIC LIFE)) \$ 10291.

5. SIMPLE PAYBACK PERIOD (1G/4) 9.97 YEARS

6. TOTAL NET DISCOUNTED SAVINGS (2N5+3C) \$ 157657.

7. SAVINGS TO INVESTMENT RATIO (SIR)=(6 / 1G)= 1.54  
(IF < 1 PROJECT DOES NOT QUALIFY)

8. ADJUSTED INTERNAL RATE OF RETURN (AIRR): 5.34 %

## Conclusion

Four of the six ECO's evaluated produce savings to investment ratios greater than 1.25. Not all of these conservation concepts can be accomplished simultaneously. ECO No. 5 is predicated on being incorporated with No. 4, and these two concepts should be considered as one.

Neither ECO No. 1 nor No. 2 is compatible with ECO No. 5, since each of them negates the availability of high energy tailgas on which ECO No. 5 depends.

ECO No. 3 can be incorporated with any combination of other mutually compatible ECO's.

Although integral implementation of ECO's No. 1 and No. 2 could be accomplished, this combination can be eliminated by inspection because No. 1 requires increased steam flow from the central plant at 300 psig, while No. 2 produces excess 100 psig steam to displace central plant steam.

The available groupings of qualifying ECO's do not produce an aggregate cost greater than \$300,000, and therefore cannot be considered for ECIP funding.

We recommend implementation of ECO's No. 7, which at current production rates, will produce calculated electrical savings of  $683 \times 10^6$  Btu/yr \$3,835 per year in electrical demand costs.



## Abbreviations

AESE: Affiliated Engineers SE, Inc.

AOP: Ammonia Oxidation Process

ASME: American Society of Mechanical Engineers

bhp: Boiler Horsepower

ECO: Energy Conservation Opportunity

(ECIP): Energy Conservation Investment Program. This is a federal government program which allocates funds for projects which increase energy efficiency.

HDC: Holston Defense Corporation

HAAP: Holston Army Ammunition Plant

Excess Air: A term used to describe the amount of air that is supplied to fossil fired boilers over and above the amount theoretically required for complete combustion.

hr/yr: hour per year

kWh: kilowatt-hour


lb/hr: pounds per hour

lb/mo: pounds per month

(LCCID): Life Cycle Cost in Design. Government software package used to evaluate projects for ECIP funding.

MBtu/hr: thousand British thermal units per hour

MMBtu/yr: million British thermal units per year

: pounds per square inch gauge

SIR: Savings to Investment Ratio

## Appendices

**DETAILED  
CALCULATIONS**



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Job No:

95094-00

Checked By:

Date:

Sheet No:

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Calculations For:

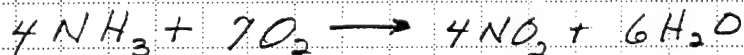
## VOLUMETRIC ANALYSIS OF PRODUCT GAS

COMPOSITE MOLECULAR WEIGHT OF AIR = 28.96 (FROM MARK'S HANDBK)

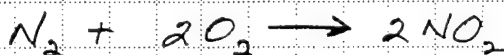
$$\text{DRY AIR SUPPLIED} = \frac{16465 \text{ \#}/\text{HR}}{28.96 \text{ \#}/\text{MOLE}} = 568.54 \text{ \# MOLES}/\text{HR}$$

$$\text{AMMONIA SUPPLIED} = \frac{1088 \text{ \#}/\text{HR}}{17.032 \text{ \#}/\text{MOLE}} = 63.88 \text{ \# MOLES}/\text{HR}$$

AMMONIA OXIDATION:



APPARENT ADDITIONAL  $\text{N}_2$  OXIDATION:



FROM MARK'S  
HANDBK

$$\text{OXYGEN SUPPLIED} = (568.54 \text{ \# MOLES}/\text{HR}) \left( \frac{20.948}{100} \right) = 119.10 \text{ \# MOLES}/\text{HR}$$

$$\text{O}_2 \text{ USED IN 100\% OXIDATION OF NH}_3 = 63.88 \text{ \# MOLES}/\text{HR} \left( \frac{7}{4} \right) = 111.79 \text{ \# MOLES}/\text{HR}$$

$$\text{O}_2 \text{ USED IN N}_2 \text{ OXIDATION} = 119.10 - 111.79 = 7.31 \text{ \# MOLES}/\text{HR}$$

$$\text{NO}_2 \text{ IN PROD. GAS} = 63.88 \left( \frac{4}{4} \right) + 7.31 \left( \frac{2}{2} \right) = 71.19 \text{ \# MOLES}/\text{HR}$$

$$\text{N}_2 \text{ USED IN N}_2 \text{ OXIDATION} = \frac{7.31}{2} = 3.66 \text{ \# MOLES}/\text{HR}$$

$$\text{H}_2\text{O FROM NH}_3 \text{ OXIDATION} = 63.88 \left( \frac{6}{4} \right) = 95.82 \text{ \# MOLES}/\text{HR}$$

$$\text{H}_2\text{O IN AIR} = \frac{0.0055 \text{ \# H}_2\text{O}/\text{DA} (16465 \text{ \# DA}/\text{HR})}{18.015 \text{ \#}/\text{MOLE}} = 5.03 \text{ \# MOLES}/\text{HR}$$



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Calculations For:

## VOLUMETRIC ANALYSIS OF PRODUCT GAS

FROM MARKS HANDBK

CONSTITUENT	# MOLES/HR IN AIR	# MOLES/HR USED/PRODUCT	# MOLES/HR IN PROD. GAS	% BY VOL DRY GAS
N <sub>2</sub>	568.54 (78.084%) = 443.94	(3.66)	440.28	85.20
ARGON	568.54 (0.934%) = 5.31	0	5.31	1.03
NO <sub>2</sub>	0	0	71.19	13.78
H <sub>2</sub> O	5.03	95.82	100.85	516.78 # MOLES/HR
O <sub>2</sub>	119.10	(119.10)	0	
			617.63	

WET GAS  
% BY VOL

N<sub>2</sub> = 71.29  
AR = 0.86  
NO<sub>2</sub> = 11.53  
H<sub>2</sub>O = 16.33

PARTIAL PRESSURE  $P_{H_2O} = (0.1633)(102 \text{ #/IN}^2)$   
 $= 16.66 \text{ PSIG.}$

ABSOLUTE PR. = 16.66 + 14.97 = 31.63 PSIA.

SATURATION TEMP. OF H<sub>2</sub>O @ 31.63 PSIA = 253.37°F → DEWPOINT



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Calculations For:

PRODUCT GAS

$$C_{P,PR.G.} = \frac{W_{N_2} C_{P,N_2} + W_{AR} C_{P,A} + W_{NO_2} C_{P,NO_2} + W_{H_2O} C_{P,H_2O}}{W_{PR.G.}}$$

$$W_{N_2} = 440.28 \text{ #MOLES/HR} (28.013) = 12333.56 \text{ #/HR}$$

$$W_A = 5.31 \text{ #MOLES/HR} (39.948) = 212.12 \text{ #/HR}$$

$$W_{NO_2} = 71.19 \text{ #MOLES/HR} (46.005) = 3275.12 \text{ #/HR}$$

$$W_{H_2O} = 100.85 \text{ #MOLES/HR} (18.015) = 1816.85 \text{ #/HR}$$

$$17637.65 \text{ #/HR}$$

$$C_{P,N_2} = 0.227 + 0.0000292(1260) = 0.264 \text{ B/#}^\circ\text{F}$$

$$C_{P,A} = 4.972/39.948$$

$$= 0.124 \text{ B/#}^\circ\text{F}$$

SEE BUFFALO  
TBL 6.

$$C_{P,NO_2} = 4.972/46.006$$

$$= 0.108 \text{ B/#}^\circ\text{F}$$

$$C_{P,H_2O} = 0.433 + 0.0000166(1260) = 0.454 \text{ B/#}^\circ\text{F}$$

$$C_{P,PR.G.} = \frac{12333.56(0.264) + 212.12(0.124) + 3275.12(0.108) + 1816.85(0.454)}{17637.65}$$

$$= 0.253 \text{ B/#}^\circ\text{F}$$



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Date:

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95094-00  
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Calculations For:

RECOVERABLE HEAT

$$Q_{\text{REC}} = W C_p (T_{\text{IN}} - T_{\text{OUT}}) = 17638(0.253)(800 - 400)/1000 \\ = 1785.0 \text{ MBH}$$

ASSUME FEEDWATER ENTERING BOILER IS 300°F @ 65 PSIG

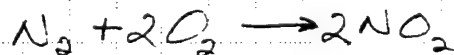
$$W_{\text{STM}} = \frac{1785000 \text{ BTU/H}}{\Delta h} = \frac{1785000}{1183.1 - 282} = 1980 \text{ \#/HR.} \\ @ 65 \text{ PSIG.}$$

VOLUMETRIC ANALYSIS - PRODUCT GAS/BLEACHING AIR:

CONSTITUENT	# MOLES/HR IN BLEACHING AIR	# MOLES/HR IN PR. GAS ENTG.	# MOLES/HR IN NEW PR. GAS	% BY VOL
N <sub>2</sub>	95.96(.78084) = 74.93	440.28	515.21	72.05
A	95.96(.00934) = 0.90	5.31	6.21	0.87
O <sub>2</sub>	95.96(.20948) = 20.10	0	20.10	2.81
NO <sub>2</sub>	0	71.76	71.76	10.04
H <sub>2</sub> O	$\frac{15.45}{18.013} = 0.86$	100.85	101.75	14.23
			715.03	

$$\text{BLEACHING AIR: } 2779 \text{ \#DA/HR} + 15.45 \text{ \#H}_2\text{O/HR} = 2794.45 \\ \text{\#MOLES \#DA/HR} = 2779/28.96 = 95.96$$

ASSUME ALL AVAILABLE O<sub>2</sub> COMBINES W/ AVAILABLE N<sub>2</sub>:







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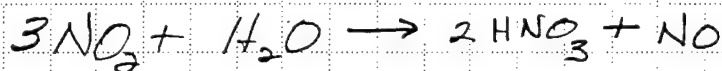
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Calculations For:

PRODUCT & TAILGAS

CONSTITUENT	# MOLES ENT. COL	# MOLES IN PROD	# MOLES IN TAILGAS
N <sub>2</sub>	515.21 $\frac{20.10}{2} = 505.16$	0	505.16
A	6.21	0	6.21
O <sub>2</sub>	0	0	0
NO <sub>2</sub>	71.76 + 20.10 = 91.86	0	0
H <sub>2</sub> O	101.75	66.39 LIQUID	4.74 VAPOR
HNO <sub>3</sub>	$\frac{91.86 \times 2}{3} = 0$	61.24	0
NO	$\frac{91.86}{3} = 0$	0	30.62
		127.63	546.73

REACTION:



$$\text{WATER IN REACTION} \rightarrow \frac{91.86}{3} = 30.62 \text{ \# MOLES/HR}$$

$$\text{WATER IN TAILGAS} \rightarrow \frac{15450 \text{ \#/HR} (0.0055 \text{ \# H}_2\text{O} / \text{ \# D.G.})}{(1.00 - 0.0055 \text{ \# H}_2\text{O} / \text{ \# D.G.}) (18.015)} = 4.74 \text{ \# MOLES/HR}$$

$$\begin{aligned} \text{PRODUCT} &\rightarrow 61.24 \text{ \# MOLES/HR} (63.013 \text{ \#/ \# MOLE}) + (66.39 \text{ \# MOLES/HR}) (18.015 \text{ \#/ \# MOLE}) \\ &= 5055 \text{ \#/HR} \end{aligned}$$

$$\% \text{ HNO}_3 = \frac{61.24 (100)}{127.63} = 47.98 \text{ BY VOLUME}$$

$$\% \text{ HNO}_3 = \frac{61.24 (63.013)}{5055} = 76.34 \text{ BY WEIGHT}$$



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Calculations For:

ABSORPTION COLUMN OUTLET FLOWS (RATED PRODUCTION)

$$61\% \text{ DILUTE } \text{HNO}_3 = \frac{50 \text{ TPD}(2000 \text{ #/T})}{24 \text{ HR} (.61)} = 6830 \text{ #/H}$$

$$\text{HNO}_3 \text{ MOL. WT.} = 63.016$$

$$\text{HNO}_3 = \frac{(0.61)(\frac{6830}{100})}{63.016} = \frac{416.7}{63.016} = 66.11 \text{ # MOLES/HR}$$

$$\text{H}_2\text{O} = \frac{(0.39)(\frac{6830}{100})}{18.016} = \frac{266.15}{18.016} = 147.85 \text{ # MOLES/HR}$$

ASSUME TAILGAS CONTAINS WATER VAPOR QUANTITY  
EQUAL TO AMOUNT PRESENT IN SATURATED AIR  
@ 60 PSIG AND 85°F.

$$\text{H}_2\text{O} = 0.0055 \text{ #/#} (15450 \text{ #/HR}) = 85 \text{ #/HR}$$

$$\text{# MOLES/HR} = \frac{85}{18.016} = 4.72$$

$$\text{SPRAY WATER REQ} = \frac{147.85}{18.016} + 4.72 - \frac{11.94}{18.016} = 9.20 + 4.72 - 0.66 = 13.26 \text{ #/HR}$$

$$\text{OR } \frac{140.63 \text{ #/HR} (18.016 \text{ #/MOLE})}{8.33 \text{ #/G} (60 \text{ M/HR})} = 5.06 \text{ GPM}$$

OR 2530 #/HR

TAIL GAS	# MOLES/HR	MOL. WT.	MOLES	
O <sub>2</sub>	12.11	32	0.38	
N <sub>2</sub>	435.64	28.016	15.55	
NO	45.82	30.008	1.53	
H <sub>2</sub> O	4.72	18.016	0.26	
	498.29		17.72	
				MOL. WT. = $\frac{498.29}{17.72} = 28.12$



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Calculations For:

PRODUCT AND TAILGAS (BY MOLAL ANALYSIS)

$$\text{SPRAY WATER ADDED} = 0.3 \text{ GPM} (8.35 \text{ #/GAL}) (60 \text{ #/HR}) \\ = 150.3 \text{ #/HR}$$

$$\text{TOTAL PRODUCT} = 5205 \text{ #/HR}$$

ABSORPTION COLUMN MASS BALANCE:

$$W_{IN} = 505.16(28.014) + 6.21(39.948) + 91.86(46.01) + 101.75(18.013) + 150 \\ = 20609 \text{ #/HR}$$

$$W_{OUT} = 505.16(28.014) + 6.21(39.948) + 4.74(18.013) + 30.62(30.01) + 5205 \\ = 20610 \text{ #/HR}$$

$$\text{TAILGAS} = 20610 - 5205 = 15405 \text{ #/HR}$$

$$\text{PRODUCT \% HNO}_3 = \frac{\text{# MOLES HNO}_3}{\text{# MOLES H}_2\text{O} + \text{# MOLES HNO}_3} = \frac{61.24(100)}{127.63 + 150.3/18.013} = 45.04\% \text{ BY VOL}$$

$$\text{PRODUCT \% HNO}_3 = \frac{61.24(63.013)(100)}{5205} = 74.14\% \text{ BY WT.}$$

CALCULATE ADDITIONAL SPRAY WATER REQUIRED TO PRODUCE 61% HNO<sub>3</sub> BY WEIGHT:

$$.61(5205 + W) = 61.24(63.013) \\ W = 112.1 \text{ #/HR}$$

$$\text{TOTAL PRODUCT} = 5205 + 112.1 \\ = 6326 \text{ #/HR}$$

$$\text{SPRAY WATER} = \frac{(112.1 + 150.3)}{8.35(60)} = 2.5 \text{ GPM}$$



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Calculations For:

ENERGY INVENTORY AT AIR PREHEATER

### EXISTING SYSTEM

#### HEAT LOSS FROM BARE PIPE:

REF. SCHULLER HEAT TRANSFER TABLES  
18"  $\phi$  @ 1200°F PIPE OPER. TEMP. - BARE - DULL

$$Q = \frac{54455 \text{ BTUH/FT (15 FT)}}{1000} = 980.2 \text{ MBH}$$

#### HEAT TRANSFERRED TO AIR:

$$Q = W C_p \Delta T = \frac{16556 (0.24) (625 - 100)}{1000}$$

$$= 2086.1 \text{ MBH}$$

#### HEAT REMOVED FROM PRODUCT GAS:

$$Q = 980.2 + 2086.1 = 3066.3 \text{ MBH}$$

#### HEAT TRANSFERRED TO WATER @ CONVERTER:

$$Q = \frac{500 (6 \text{ GPM}) (\Delta T)}{1000} = \frac{500 (77) (140 - 65)}{1000}$$

$$= 2887.5 \text{ MBH}$$



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Calculations For:

COOLING WATER AT CASCADE COOLER

### EXISTING SYSTEM

$$Q = (\text{LBS EVAP/HR})(950) + (\overset{15445}{16020} - \text{LBS EVAP})(100 - 75)$$

$$\text{LBS EVAP/HR} = W$$

$$\overset{4018.7}{3413.7}(1000) = 950 W + \overset{15445}{16020}(25) - 25 W$$

$$W = \frac{\overset{4018}{3413700} - \overset{386125}{250000}}{925} = \frac{3927}{3665} \text{ #/HR}$$

$$\text{DRAIN} = 15445 - 3927 = 11520 \text{ #/HR}$$



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Calculations For:

ENERGY INVENTORY AT ABSORPTION COLUMNS

### EXISTING SYSTEM

ADDITIONAL WATER CONDENSED:

$$H_2O = (0.0065 \text{ #H}_2\text{O/\# DRY GAS}) (19900 \text{ #/HR}) - 85 \text{ #/H}$$
$$= 44.35 \text{ #/HR}$$

$$\text{HEAT REMOVED} = \frac{44.35(h_{fg})}{1000} = \frac{44.35(873)}{1000} = 38.7 \text{ MBH}$$

APPROX. HEAT REMOVED FROM GAS:

$$Q = W C_p \Delta T = \frac{15450(0.25)(105-85)}{1000}$$
$$= 115.9 \text{ MBH}$$

FROM TECHNICAL REPORT NO. HDC-39-77,

APPARENT ACID CHEMICAL HEAT LEAVING

THE COLUMN IS 112.5 MBH (SEE REFERENCE MATERIAL IN APPENDIX)

RQ.D. COOLING WATER:

$$CH \text{ WTR. GPM} = \frac{(38.7 + 115.9)}{(2)(50)(45-35)} = 15.5 \text{ OR } 7750 \text{ #/HR}$$

$$RW \text{ GPM} = \frac{38.7 + 115.9}{50(65-75)} = 30.9 \text{ OR } 15445 \text{ #/HR}$$



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Calculations For:

WATER CHILLER

ASSUME HEAT REJECTED IN EXTENDED  
ABSORPTION COLUMN IS ONE HALF THE  
TOTAL FOR BOTH COLUMNS.

ASSUME CHILLER STEAM REQUIREMENTS  
ARE 22.5 #/HR STEAM PER TON OF REFRIG.

$$\text{TONS} = \frac{(115.9 + 38.7) \text{ MBH}}{(2) 12,000 \text{ MBH/TON}} = 6.44 \text{ TONS}$$

$$\text{STEAM} = 6.44 \times 22.5 = 145 \text{ #/HR}$$

BAROMETRIC CONDENSER:

$$\begin{aligned} \text{HEAT GAIN} &= 145 (h_{fg}) = 145 (1045.8) \quad * \text{ASSUME} \\ &= 151640 \text{ BTUH} \quad \text{85}^\circ \text{ COOL.} \\ &\quad \text{TEMP.} \end{aligned}$$

FOR  $\Delta T = 20^\circ \text{F}$ :

$$\text{GPM} = \frac{151640}{500 (20)} = 15 \text{ OR } 7580 \text{ #/HR}$$



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Calculations For:

TAILGAS (BY MOLAL ANALYSIS)

$$C_{PTG} = \frac{W_{N_2} C_{PN_2} + W_{AR} C_{PAR} + W_{NO} C_{PNO} + W_{H_2O} C_{PH_2O}}{W_{TG}}$$

$$W_{N_2} = 505.16(28.013) = 14151.05$$

$$W_{AR} = 6.21(39.948) = 248.08$$

$$W_{NO} = 30.62(30.01) = 918.91$$

$$W_{H_2O} = 4.74(18.015) = \frac{85.39}{15403.43}$$

CALCULATE  $C_p$  @  $350^\circ F$  ( $810^\circ R$ )

$$C_{PN_2} = 0.227 + 0.0000292(810) = 0.251$$

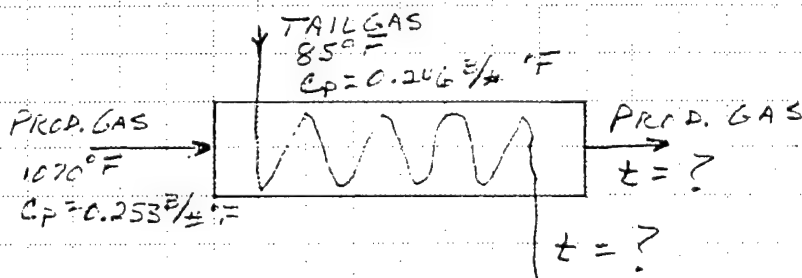
$$C_{PAR} = 4.972/39.948 = 0.124$$

$$C_{PNO} = 4.972/30.01 = 0.177$$

$$C_{PH_2O} = 0.432 + 0.0000156(810) = 0.446$$

$$C_{PTG} = \frac{14151.05(0.251) + 248.08(0.124) + 918.91(0.177) + 85.39(0.446)}{15403.43}$$

$$= 0.246 \text{ B/}\pm^\circ F$$







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Calculations For:

TAILGAS HEATER

CALCULATE HEATER "EFFECTIVENESS" USING EXISTING SYSTEM PARAMETERS:

$$EFF = \frac{T_{TG,OUT} - T_{TG,IN}}{T_{PG,IN} - T_{TG,IN}} = \frac{785 - 85}{1070 - 85} = 0.711$$

USING CALCULATED EFF, DETERMINE PROCESS PARAMETERS OF THE INSULATED SYSTEM:

$$T_{TG,OUT} = T_{TG,IN} + 0.711(T_{PG,IN} - T_{TG,IN}) = 85 + 0.711(1205 - 85) = 881^{\circ}F$$

$$Q_{RECUV} = W_{TG} C_{PG} (T_{TG,OUT} - T_{TG,IN}) = 15403.43(0.246)(881 - 85) = 3,017,450 \text{ BTU/H}$$

$$T_{PG,OUT} = T_{PG,IN} - \frac{Q_{RECUV}}{W_{PG} C_{PPG}} = 1205 - \frac{3,017,450}{17637.65(0.253)} = 529^{\circ}F$$

$$Q_{EXISTG} = W_{TG} C_{PG} (T_{TG,OUT} - T_{TG,IN}) = 15403.43(435 - 85)(0.246) = 1,326,235 \text{ BTU/H}$$

$$\Delta Q = 3,017,450 - 1,326,235 = 1,691,215 \text{ BTU/H}$$

\*ALSO  $\Delta Q$  SHOULD BE APPROXIMATELY EQUAL TO THE REDUCTION IN PIPE LOSS TO ATMOS. BY ADDING INSUL.

$$Q_{INSUL SAVS} = 980220 - 41900 + 554300 - 34900 = 1,457,700 \text{ BTU/H}$$

$$\% \text{ ERROR} = \frac{1,691,215 - 1,457,700}{1,691,215} \times 100 = 13.8\%$$

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Calculations For:

TAILGAS PIPING

CALCULATE TAILGAS VELOCITY IN PIPING TO TURBINE:

MTL. - 6" HCl - USE ASTM A312 GRADE TP321

SCH. NO. = 1000 P/SB

P = 90 PSIG @ 800°F

SE = 12850 PSI

$$\text{SCH. NO.} = \frac{1000(90)}{12850} = 7$$

USE SCHEDULE 10S → ID = 6.357 IN

$$\text{AREA} = 31.7 \text{ IN}^2$$

$$\frac{P_1 V_1}{R T_1} = \frac{P_2 V_2}{R T_2}$$

STANDARD ATMOSPHERE: 518.7°R, 14.696 PSIA, 0.07651 #/FT<sup>3</sup>

$$V_2 = \frac{14.696 \left( \frac{1}{0.07651} \right) (1260^\circ\text{R})}{518.7 (90 + 14.696)} = 4.457 \text{ FT}^3/\#$$

$$V = \frac{15403.43 \text{ #/HR} (4.457 \text{ FT}^3/\#)}{60 \text{ #/HR} (31.7 \text{ IN}^2 / 144 \text{ IN}^2/\text{FT}^2)} = 5197 \text{ FPM}$$

PIPE DEVELOPED LENGTH = 75 FT.

USE EQUIVALENT LENGTH = 75(1.33) = 100 FT



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Calculations For:

TAILGAS PIPING

$$N_{RE} = \frac{VDP}{\nu} = \frac{5197 \text{ FT/MIN} (6.357 \text{ IN}) (60 \text{ MIN/HR})}{12 \text{ IN/FT} (4.457 \text{ FT}^3/\#) (0.081 \text{ #/FT-HR})}$$
$$= 457,559$$

$$\Delta P = \frac{3.4 \times 10^{-6} f L W^2 \nu}{d^5} = \frac{3.4 \times 10^{-6} (0.008) (100) (15403.43)^2}{(6.357)^5 (1/4.457)}$$
$$= 0.28 \text{ PSI}$$

ASSUMING TAILGAS PRESSURE LEAVING TAILGAS HEATER IS 60 PSIG, CALCULATE STEAM PRODUCTION CAPABILITY OF HEAT RECOVERY BOILER ASSUMING PRODUCT GAS TEMPERATURE LEAVING THE BOILER OF 400°F, FEEDWATER ECONOMIZER OUTLET (BOILER INLET) TEMPERATURE OF 300°F, AND 50°F SUPERHEAT.

$$W_{STM} = \frac{W_{PG} \cdot C_{PG} (T_{PG,IN} - T_{PG,OUT})}{(h_{STM,OUT} - h_{FW,IN})} = \frac{17637.65 (0.253) (524 - 400)}{(1210.0 - 280)}$$
$$= 619 \text{ #/HR @ } 360^\circ\text{F \& } 78 \text{ PSIA}$$

$$W_{WET GAS} = W_{T.G.} + W_{STM} = 15403.43 + 619 = 16022 \text{ #/HR}$$

$$\nu_{STM} = 6.045 \text{ FT}^3/\text{#} \quad \text{FROM KEENAN \& KEYES}$$

$$\nu_{WET GAS} = \frac{6.045 (619) + 4.457 (15403.43)}{16022} = 4.518 \text{ FT}^3/\text{#}$$



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Calculations For:

TABLE 1

AMMONIA VAPORIZER:

$$Q_{GAIN_{SM}} = 694 \text{ \#}/\text{HR} (1273 \text{ B}/\text{\#} - 244 \text{ B}/\text{\#}) = 714,126 \text{ BTU/H}$$

$$Q_{LOSS_{COND.}} = 694 \text{ \#}/\text{HR} (1 \text{ B}/\text{\#F}) (275^\circ - 60^\circ) = 149,210 \text{ BTU/H}$$

MIXER:

$$Q_{TRANS(AIR)} = 16556 \text{ \#}/\text{HR} (0.24 \text{ B}/\text{\#F}) (625 - 580^\circ) = 178,804 \text{ BTU/H}$$

$$Q_{TRANS(NH_3)} = 1080 \text{ \#}/\text{HR} (0.54 \text{ B}/\text{\#F}) (580^\circ - 275^\circ) = 177,876 \text{ BTU/H}$$

CONVERTOR:

$$CLNG. WTR: Q_{REJ.} = 38499 \text{ \#}/\text{HR} (1 \text{ B}/\text{\#F}) (140 - 65) = 2,887,425 \text{ BTU/H}$$

$$Q_{REACTION} = 7136.1 \text{ BTU/H} - \text{SEE NEXT SHEET}$$

AIR PREHEATER:

$$Q_{REJ. (AIR)} = 16556 \text{ \#}/\text{HR} (0.24 \text{ B}/\text{\#F}) (625 - 100) = 2,086,056 \text{ BTU/H}$$

REF. SCHULLER HT. TRANSF. TABLE

$$Q_{REJ. (ATMOS)} = 54455 \text{ BTU/H/FT} (15 \text{ FT}) = 816,825 \text{ BTU/H}$$

$$T_{PG, OUT} = T_{PG, IN} - \frac{Q_{REJ. (AIR)} + Q_{REJ. (ATMOS)}}{W_{PG} C_{PG}} = \frac{2,086,056 + 816,825}{17644 (0.253)} = 819.7$$

TAILGAS HEATER:

$$T_{TG, OUT} = T_{TG, IN} + EFF (T_{PG, IN} - T_{TG, IN}) = 85 + 0.711 (819.7 - 85) = 607.4^\circ \text{F}$$

$$Q_{TG} = W C_p \Delta T = 15450 (0.248) (607.4 - 85) = 2,001,528 \text{ BTU/H}$$

$$Q_{REJ. (ATMOS)} = 9997 (21) = 209,937$$

$$T_{PG, OUT} = T_{PG, IN} - \frac{(Q_{TG} + Q_{REJ. (ATMOS)})}{W_{PG} C_{PG}} = 819.7 - \frac{(2,001,528 + 209,937)}{17644 (0.253)} = 324.3$$

CASCADE COOLER:

$$Q_{REJ. COND.} = W_{DG} C_p \Delta T = 17092 (0.253 \text{ B}/\text{\#F}) (607.4 - 105) = 2,172,516 \text{ BTU/H}$$

$$Q_{REJ. CONDENS.} = 673,700 \text{ BTU/H} - \text{SEE NEXT PAGE}$$

$$Q_{REACT} = 0.80 (6086.7) = 4,869,400 \text{ BTU/H}$$



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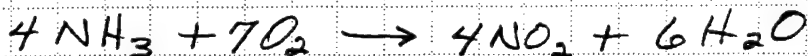
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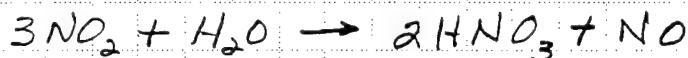
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Calculations For:

# REACTION HEAT TABLE 1



CONSTITUENT	HEAT OF COMBUSTION	CONSTITUENT LBS/HR	SYSTEM NET HEAT
NH <sub>3</sub>	1163 B/#	1088	(1,265,344 BTU/H)
O <sub>2</sub>	-	-	-
NO <sub>2</sub> (1443.7 B/#)	33.1 x 10 <sup>3</sup> J/mol (9.48 x 10 <sup>9</sup> B/I)	2939	(4,242,963 BTU/H)
		1287	(1,858,042 BTU/H)
H <sub>2</sub> O	6827 B/# (LIQUID)	1726.2	11,784,767 BTU/H
	h <sub>g</sub> - h <sub>f</sub> = 1856.0 - 313.8 = 1542.2		2,717,665 BTU/H
			NET = 7,136,082 BTU/H



CONSTITUENT	HEAT OF COMBUSTION	CONSTITUENT LBS/HR	SYSTEM NET HEAT
NO <sub>2</sub>	(1443.7 B/#)	4226	6,101,076
H <sub>2</sub> O	6827 B/# (LIQUID)	552	(3,768,504 BTU/H)
	h <sub>g</sub> - h <sub>f</sub> = 1530.3 - 309.8 = 1220.5		(673,716 BTU/H)
HNO <sub>3</sub>	1190 B/# (LIQUID)	4025	4,789,750 BTU/H
	h <sub>g</sub> - h <sub>f</sub> = 206 B/#		829,150
NO	(1296 B/#)	919	(1,191,024 BTU/H)
			NET 6,086,732



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Calculations For:

TABLE 1

### PRODUCT

SOLUTION - 198.2 # MOLES/HR

HNO<sub>3</sub> - 61.2 # MOLES/HR

REFERENCE "HEAT OF DILUTION OF ACIDS" TABLE

$$\eta = \frac{198.2 - 61.2}{61.2} = 2.2$$

$$\Phi_L = 2952 \text{ cal/mol} = 12351.168 \text{ Joules/mol}$$

$$\begin{aligned} \text{HEAT OF DILUTION} &= 12351.168 \frac{\text{Joules}}{\text{mol}} (61.2 \frac{\# \text{ MOLES}}{\text{HR}}) (9.48 \times 10^{-4} \frac{\text{B}}{\text{Joule}}) \\ &= 716 \text{ BTU/H} \end{aligned}$$

HEAT ABOVE AMBIENT:

$$\begin{aligned} Q &= W C_p \Delta T = 6830 \frac{\#}{\text{HR}} (0.64 \frac{\text{B}}{\# \cdot \text{F}}) (87 - 60) \\ &= 118022 \text{ BTU/H} \end{aligned}$$

ABSORPTION COLUMNS:

$$\begin{aligned} Q_{\text{REJ GAS}} &= W_{\text{DG}} C_p \Delta T = 17092 (0.253) (105 - 85) \\ &= 86,485 \text{ BTU/H} \end{aligned}$$

$Q_{\text{REJ CONDENS}} = 0 \rightarrow$  ALL CONDENSATION IN  
PRODUCT GAS OCCURS IN  
CASCADE COOLER CALCS.

$$Q_{\text{REAT.}} = 0.2 (6086.7) = 1217.300 \text{ BTU/H}$$



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TABLE 1

TURBINE:

FROM KEENAN & KEYE @ 324°F (784°R):  $P_{r1} = 5.144$ ,  $h_1 = 187.92$

$$P_{r2} = P_{r1} \left( \frac{P_2}{P_1} \right) = 5.144 \left( \frac{15}{73} \right) = 1.057$$

$$h_{2\text{THEOR}} = 119.4$$

$$h_2 = h_1 - \epsilon_{\text{TURB}} (h_1 - h_{2\text{THEOR}}) = 187.92 - 0.725 (187.92 - 119.4) \\ = 138.2 \text{ B/lb}$$

$$T_2 = 578^\circ\text{R} \text{ OR } 118^\circ\text{F}$$

$$W_{K\text{TURB}} = \frac{W_{T6} \Delta h}{2545} = \frac{15450 (187.92 - 138.2)}{2545} = 301.8 \text{ HP}$$

$$Q_{\text{TURB}} = 301.8 (2545) = 768174 \text{ BTU/H}$$

$$Q_{\text{REJATM}} = W C_p \Delta T = 15450 (0.248) (118 - 60) = 222233 \text{ BTU/H}$$

$$Q_{\text{REJEXH}} = W C_p \Delta T = 15450 (0.248) (607.4 - 60) = 2097418$$

AIR COMPRESSOR:

FROM JOY MFR. CO. TEST PERFORMANCE  
CURVE EXTRAPOLATED TO 4195 SCFM  
DELIVERY — USE 1095 HP

$$Q_{\text{MTR}} = \frac{(1095 - 302) (2545)}{1000} = 2018.2 \text{ MBH}$$



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Calculations For:

TURBINE DRIVE FOR AIR COMPRESSOR ECO#1

USING FIG. 4 (ATTACHED) FROM MARK'S HANDBOOK:

$$\text{RATIO OF COMP.} = \frac{(115 + 14.7)^{1/2}}{14.7} = 2.974$$

$$\text{HP} = \frac{69(4197 \text{ SCFM})(1440)(1.03)(2)}{100} = 859$$

$$\text{HP} = \frac{859}{.748} = 1152$$

FROM MOLLIER DIAGRAM:

$$\Delta h = 1271 \text{ B/H} - \frac{1054}{217} \text{ B/H} = 829 \text{ B/H}$$

STEAM REQ. @ 75% TURB. EFF:

$$W = \frac{859 \text{ HP}(2545 \text{ B/HP})}{829(.75)} = \frac{13152}{217} \text{ #/HR} = 12732 \text{ #/HR}$$

POWER ENTER FOR CONDENSER:

$$\text{COND. TEMP} = 101^\circ \text{F @ } 2" \text{ Hg}$$

FOR 95% QUALITY STEAM:

$$h = h_f + x(h_g - h_f) = 69.1 + .95(1036.4) = 1053.9$$

$$Q_{\text{COND}} = \frac{12732(1053.9 - 69.1)}{1000} = \frac{13228}{1000} = 13.228 \text{ MBH}$$

$$\text{REV. WTR} = \frac{Q_{\text{COND}}}{500(\Delta T)} = \frac{13228}{500(95 - 65)} = \frac{880}{1} = 880 \text{ GPM}$$



$$\Sigma_{dnq} = 227[(1.08R_c)^{0.203} - 1] \quad (4)$$

$\Sigma_{dnq} = 0.0456 \bar{m} c_p \Delta t$ , where  $c_p$  is the specific heat at constant volume and  $\Delta t$  is the isentropic temperature rise. A multiplier of 0.147 applied to the above  $\Sigma$  values gives the bhp 100 ft<sup>3</sup>/min at 14.4 psia and 60°F. Figure 4 illustrates a similar empirical solution for  $\Sigma$ , wherein an arbitrary pressure ratio efficiency of 68 percent is applied at 1.5  $R_c$ , 78 percent at 1.2  $R_c$ , and 87 percent at 1.0  $R_c$ . Mechanical efficiency of 87 percent is widely accepted, which includes loss allowances of 3 percent for piston-ring friction and piston-rod packing, 3 percent for gearing friction of the crosshead, slipper rings, connecting-rod pins, and crankshaft bearings. The heat losses are dissipated by convectional air circulation in the sizes under 300 hp and into the lubricant system in larger sizes. The ring and packing losses are mostly absorbed by the jacket-water system. Where the cylinder power is less than 100 hp, these losses should be doubled.

#### Temperature Rise

Compression is essentially an adiabatic function, especially when referred to the internal cylinder conditions. The pressure-temperature rise follows the equation

$$T_2 = T_1(KR_c)^{\sigma/\eta} \quad (5)$$

where  $\eta$  represents the heat leak factor applied in a manner consistent with the thermal efficiency. These factors are less than 1.05 for normal water-jacket cylinders, 1.09 for dry-cooled cylinders, 1.11 for forced-air-cooled cylinders with fins, 1.15 for high-velocity water-jacket cooling and the expansion cycle, curve *CFD* on Fig. 1. There was a time when water was injected into the suction of air compressors to reduce the cylinder temperature; when the speed of machinery was increased and the clearance volume reduced, the practice was found to be hazardous. The temperature drop was substantial,  $\eta = 1.75$ . The scheme is still applied in chemical processes to wash out unsaturated gums and to suppress the high temperature of exothermic gases. The liquid is usually a light solvent of the same character as the gas and is injected into the suction line. A short, 10-s blast of steam for 2 or 4 h can usually clear the gums from a cylinder. The temperature behavior is only consistent below 4  $R_c$ ; and this, the cylinder cooling effect is perceptible because of the reduced mass flow at higher  $R_c$  operation. European practice of process sizing includes a **warm-up** factor, which assumes the gas is heated 20 to 40°F in passing through the cylinder and suction valves. Such a correction complements the volumetric efficiency by a judgment factor of 0.95 to 1.0. Thermocouple probes in the suction valve and in the gas stream show no such evidence at the ambient-temperature range. American practice has always disregarded such corrections. The warm-up factor also allows for valve and piston-ring leakage. If such leakage is perceptible, the temperature rise is usually cumulative and readily detectable by thermometry.

#### Compression Efficiency

Compression efficiency is an approximate method of accounting for all the power losses that occur between stagnation and discharge pressures. It presumes that all valve and piping channels offer equal resistance and that the resistance of the gas is inconsequential.

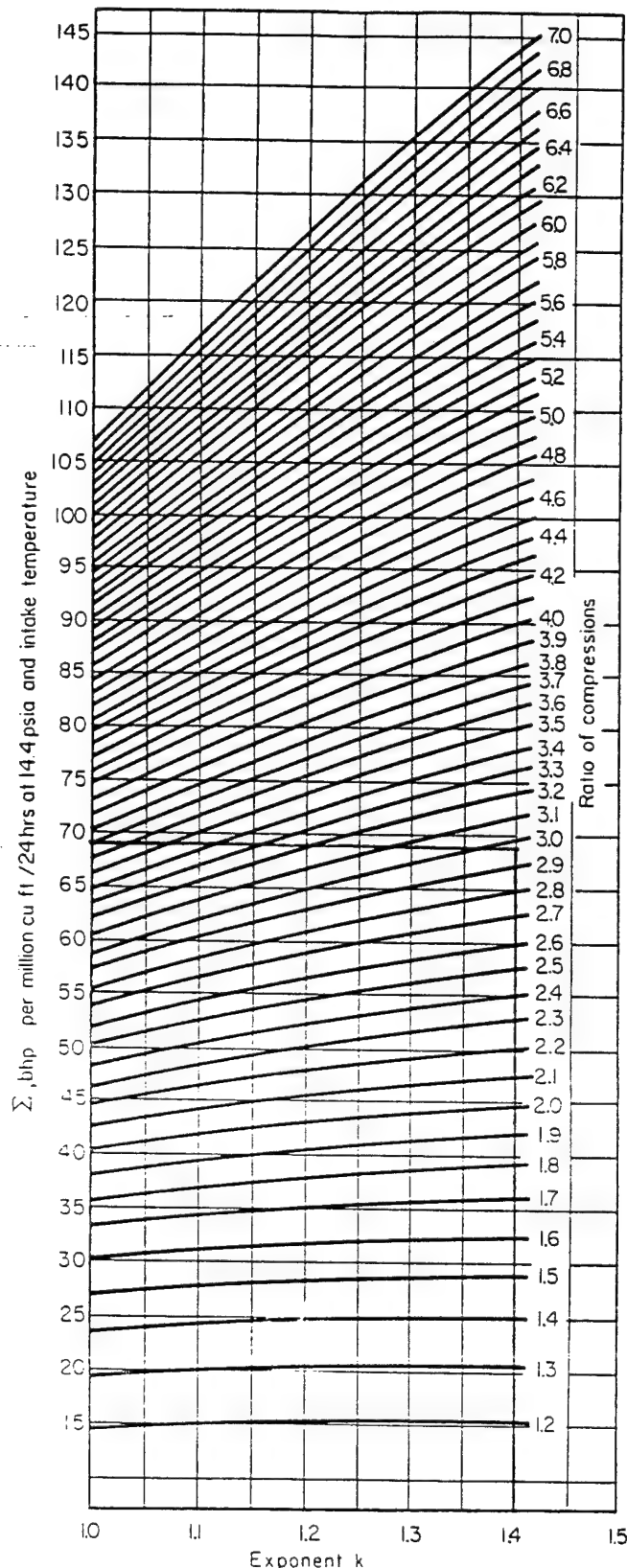
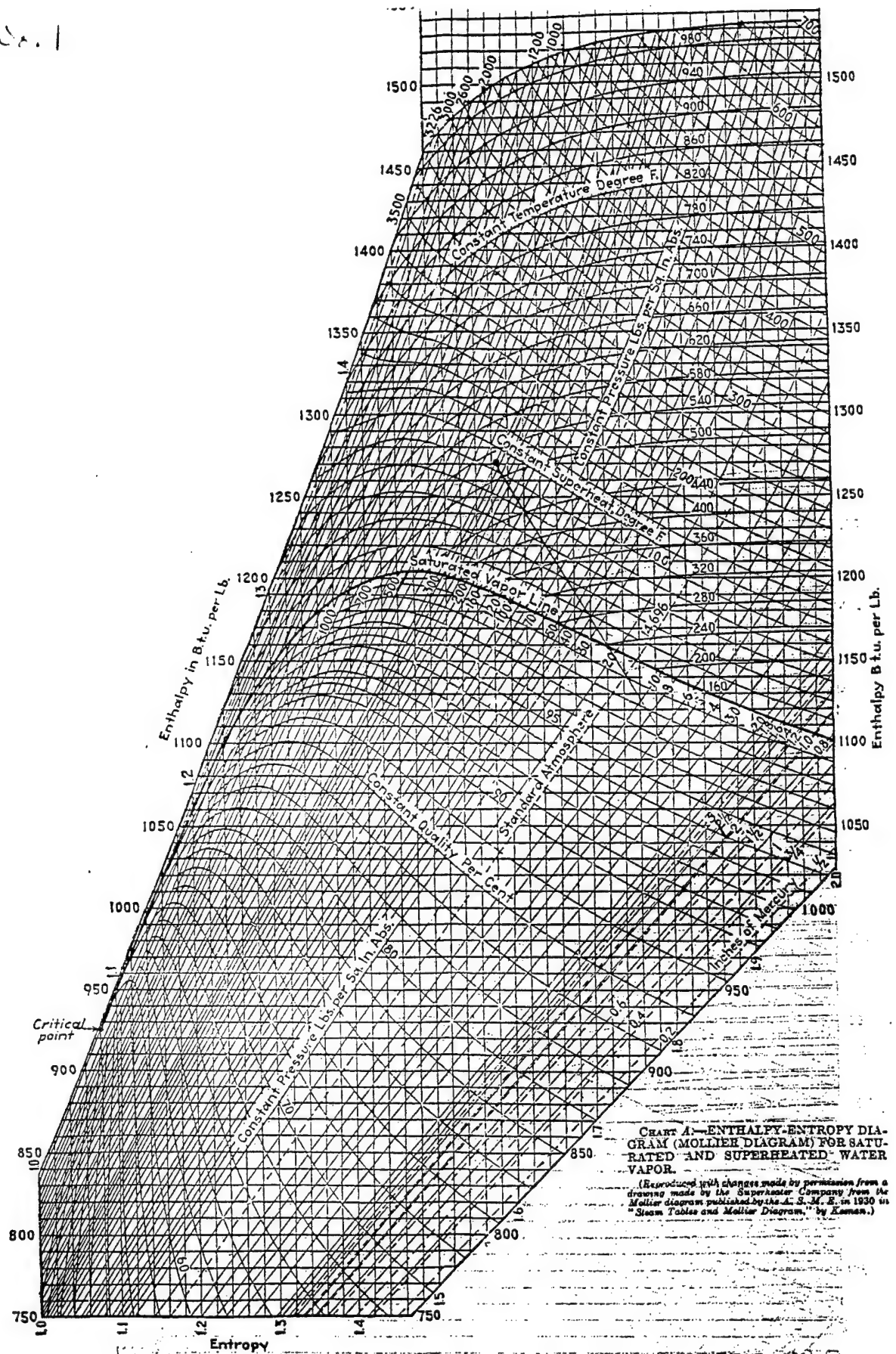


Fig. 4 Approximate horsepower to compress air or gas. If single-stage, multiply cubic feet actual capacity of free gas per minute by 1,440 to obtain capacity in millions of cubic feet per 24 h. Then capacity in 24 h times horsepower per million as obtained from the chart will give the total horsepower. If two-stage, take the square root of the total number of compressions. Read the horsepower from the chart for this ratio, multiplying the same for the two stages, to which add 3 percent for cooler loss. Note that horsepower is for 14.4 psia intake. If horsepower based on capacity at 14.7 psia, add 2 percent to horsepower.

$$\left( \frac{15}{1.2} \right)^{1.2} = 69.4 \quad \text{HP} = 69.4 \left( \frac{1.2}{1.0} \right)^{1.2} = 7.59$$

ECO No. 1



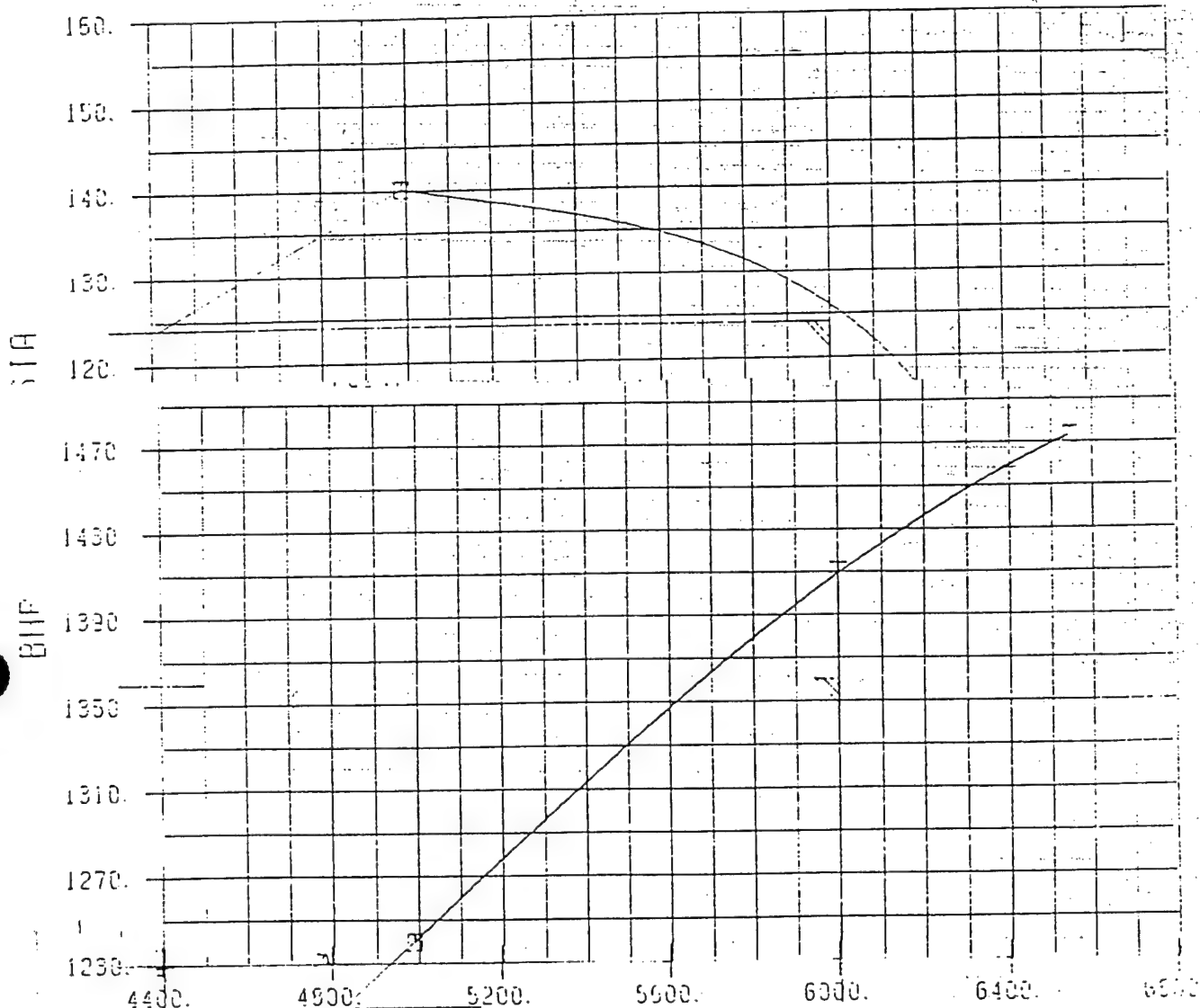
# JOY MANUFACTURING CO. BUFFALO, N.Y.

TEST PERFORMANCE F07693M1 CUSTOMER WITNESS TEST

\*7693\*

HOLSTEN DEFENSE CORP

14705Z



SCFM (avg) 14.70 60 0  
1150

1110  
1070  
← USE 1095 HP



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Calculations For:

ECO No. 1

INACTIVE HEATER LOSS TO ATMOS:

$$Q = \frac{21 \text{ FT} (33526 \frac{\text{BTU}}{\text{FT}})}{1000} = 704.0 \text{ MBH}$$

$$Q = W C_p \Delta T$$

APPARENT PRODUCT GAS  $C_p$  FROM EXISTG. SYST. CALCS:

$$Q_{\text{EX}} = 1895,400 = 17644 (C_{p_{\text{EX}}}) (1070 - 785)$$

$$C_{p_{\text{EX}}} = 0.377 \text{ B/}\text{#}\text{F}$$

$$1895400 = 17644 (0.377) (1070 - T_{\text{LUG}})$$

$$T_{\text{LUG}} = 1070 - \frac{1895400}{17644 (0.377)} = 964^\circ \text{F}$$

CASCADE CARBIDE DRAIN:

$$Q = (\text{#}/\text{HRE}) h_{fg} + (15445 \text{ #}/\text{H} - \text{#}/\text{HRE}) \Delta T$$

$$Q = W C_p \Delta T = \frac{17644 (0.377) (965 - 105)}{1000} = 5720.5 \text{ MBH}$$

$$\begin{aligned} \text{#}/\text{HRE EVAP} &= \frac{5720508/\text{H} - (15445/\text{H}) (18^\circ - 75^\circ)}{950 - 25} \\ &= 5767 \text{ #}/\text{H} \end{aligned}$$

$$\text{DRAIN} = 15445 - 5767 = 9678 \text{ #}/\text{H} \text{ OR } 196 \text{ GPM}$$



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Calculations For:

ECO No. 1

TAIL GAS RELEASE TO ATMOSPHERE.

$$Q = W C_p \Delta T = 15450(0.248)(85 - 60)/1000 \\ = 95.8 \text{ MBH}$$

ELECT ENERGY SAVINGS

$$\frac{1354.1 \text{ MBH}(1152 \text{ H/YR})}{1000} = 1560 \text{ MILLION BTU/YR}$$

$$\text{ADDITIONAL STEAM REQ.} = \frac{13432 \text{ \# / HR}(1285 - 1105.7) \text{ B/\#}(1152 \text{ \# / YR})}{1000000} \\ = 2774 \text{ MILLION BTU/YR}$$



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Calculations For:

TABLE 2

AMMONIA VAPORIZER, MIXER, CONVERTER AND AIR  
PREHEATER CONDITIONS IDENTICAL TO TABLE 1  
CALCS.

TAILGAS HEATER:

REF. SCHULLER HT. TRANSF. TABLE

$$Q_{RET_{TGP}} = 33526 (21) = 704046 \text{ BTU/H}$$

$$\Delta T_{PG} = \frac{704046}{17644 (0.253)} = 157.7^\circ$$

$$T_{LUG} = 1070 - 157.7 = 912^\circ\text{F}$$

CASCADE COOLER:

$$Q_{RET_{GAS}} = W_{DG} C_p \Delta T = 17092 (0.253) (912 - 105) = 3,489,691 \text{ BTU/H}$$

$$Q_{RET_{CONDENS}} = 673700 \text{ BTU/H} - \text{SAME AS TABLE 1}$$

$$Q_{REACT} = 4869400 \text{ BTU/H} - \text{" " " "}$$

ABSORPTION COLUMNS:

SAME AS TABLE 1

STEAM TURBINE:

$$Q_{GAIN} = 1095 \text{ HP} (2545 \text{ B/HP}) = 2,786,775 \text{ BTU/H}$$

$$W_{STM} = \frac{Q_{GAIN}}{\Delta h_{STM}} = \frac{2786775}{1271 - 1054} = 12,842 \text{ \#/HR}$$

$$Q_{RET} = W_{STM} \Delta h_{STM} = 12842 (1105.7 - 69.1) = 13,312,017 \text{ BTU/H}$$

$$Q_{RET_{COND}} = 12842 (1) (110 - 60) = 526.5$$

$$Q_{REC} = W_{CON} C_{p,CON} \Delta T = 12842 (1) (101 - 60) = 526522 \text{ BTU/H}$$

$$Q_{LOST} = 13312.0 - 526.5 = 12785.5$$



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Calculations For:

TABLE 2

PRODUCT : SAME AS TABLE 1

STACK LOSS :

$$\begin{aligned} Q_{\text{RET}} &= W C_p \Delta T = 15450(0.248)(85-60) \\ &= 95790 \text{ BTU/H} \end{aligned}$$



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Calculations For:

ECO No. 2

HEAT LOSS FROM BARE PIPE:

18"  $\phi$  PIPE @ 735°F OPER. TEMP. DULL:

$$Q = \left[ (19265 - 9997) \frac{(135)}{200} + 9997 \right] \frac{21 \text{ FT}}{1000} = 341.3$$

HEAT TRANSFERRED TO DOWNTHERM:

FROM EXISTING SYSTEM CALCS:

$$Q_{\text{TAILGAS}} = 1341.1 \text{ MBH}$$

APPARENT PROD. GAS SPECIFIC HEAT:

$$C_p = \frac{1341100}{(17644 \text{ T/HR})(1070 - 755)} = 0.267 \text{ B/LB}^\circ\text{F}$$

$$Q_{\text{PROD.}} = \frac{17644 \text{ T/HR} (0.267 \text{ B/LB}^\circ\text{F})(1070 - 400)}{1000} = 3156.3 \text{ MBH}$$

TAILGAS EXHAUST TO ATHERMOS:

$$Q = W C_p \Delta T = \frac{15450 (0.248) (85 - 65)}{1000} = 76.6 \text{ MBH}$$





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Calculations For:

ECO No. 2

### DOWNTHEM PARAMETERS

$$\begin{aligned} \text{PUMP SUCTION TEMP} &= \frac{\text{STM TEMP} + \text{PR. GAS LUG. TEMP}}{2} \\ &= \frac{338 + 400}{2} = 369^{\circ}\text{F} \end{aligned}$$

USE 725°F ENTERING BOILER

$$Q = W C_p \Delta T \quad \text{REF. TECHNICAL DATA REF. FROM TRANTER CATALOG.}$$

$$W = \frac{3156300 \text{ BTU/H}}{(0.55 \text{ Btu/lb}^{\circ}\text{F})(725^{\circ}\text{F} - 369^{\circ}\text{F})} = 16120 \text{ #/HR}$$

$$\text{GPM} = \frac{16120 \text{ #/HR} (7.48 \text{ gal/ft}^3)}{50 \text{ #/ft}^3 (40 \text{ ft/HR})} = 40 \text{ GPM}$$



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Calculations For:

TABLE 3

AMMONIA VAPORIZER, MIXER, CONVERTER AND AIR PREHEATER: SAME AS TABLE 1

DOWTHERM HEATER: (PROD. GAS COOLED TO 400°F - SEE SCOPE)

$$Q_{RET} = W C_p \Delta T = 17644 (0.253) (1070 - 400) = 2,990,834 \text{ BTU/H}$$

← REF SCHULLER HT. TRANSF. TABLE

$$Q_{LOSS} = \left[ (19265 - 9997) \left( \frac{135}{200} \right) + 9997 \right] (15 \text{ FT}) = 243,794 \text{ BTU/H}$$

CASCADE COOLER:

$$Q_{PROJENS} = W_{PG} C_p \Delta T = 17092 (0.253) (400 - 105) = 1,275,661$$

$$Q_{RET \text{ CONDENS}} = \text{SAME AS TABLE 1} = 673700 \text{ BTU/H}$$

ABSORPTION COLUMNS: SAME AS TABLE 1

AIR COMPRESSOR:

$$Q_{GN} = 859 (2545) = 2,186,300$$

$$Q_{RET} = \text{SAME AS TABLE 1}$$

FINAL BLCHR: " " "

STACK LOSS:

$$Q_{RET} = W C_p \Delta T = 15450 (0.248) (85 - 60) = 957,900 \text{ BTU/H}$$

$$\text{STEAM: } W = \frac{Q_{RET}}{\Delta h} = \frac{2747,000}{(1189 - 168)} = 2690 \text{ \# / HR}$$



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Calculations For:

FILTERED WATER COST - ECO 3

UNIT COST OF FILTERED WATER FROM STEAM  
COST CALC'S BY J. BOUCHILLON IN MARCH, 1995:

\$148 PER MILLION GALLONS.

SEE APPENDIX  
REFERENCE  
MATERIAL

PRESENT ANNUAL CONSUMPTION =  $540 \frac{\text{GAL}}{\text{M}} (60 \frac{\text{M}}{\text{HR}}) (1152 \frac{\text{HR}}{\text{YR}})$

= 37,324,800 GAL/YR

ANNUAL COST =  $\frac{\$148.00 (37324800)}{1000000} = \$5524/\text{YR.}$

WATER SAVED =  $540 \text{ GPM} - 5.7 - 11.5 = 522.8 \text{ GPM}$

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Calculations For:

ECO No. 3

EQUIPTCLNG. WATER FLOWLWT

CONVERTER

77 GPM

140°F

CASCADE CLR

24 GPM

100°F

AIR COMP.

156 GPM

104°F

109 GPM

104°F

174 GPM

101°F

540 GPM @ MIXED TEMP = 108°F

AIR COMP. BALANCED FOR 85°F EWT

CONVERTER SHOULD BE OKAY W/ 160°F LWT

CONSIDER INCREASING FLOW @ ABSORPTION  
TOWERS FOR 4° ΔT RATHER THAN 10° ΔT.

$$\text{GPM} = \frac{115900 \text{ BTU/H}}{500 (4)} = 58 \text{ GPM} - 28988 \text{ \# / HR}$$

CASCADE CLR DRAIN:

$$Q = W(950) + ((58)(8.33)(60) - W)(100 - 89)$$

$$W = 3940 \text{ \# / HR}$$

$$\text{DRAIN} = 58(8.33)(60) - 3940 \text{ \# / HR} = 25050 \text{ \# / HR}$$

OR 50 GPM @ 100°F

$$\text{TOWER FLOW} = 77 + 50 + 156 + 109 + 174 = 566 \text{ GPM}$$



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Calculations For:

ECO No. 3

## TOWER SELECTION:

566 GPM

108°F EWT

85°F LWT

76°F W.B.

MARLEY NC 3011

± 85000 CFM

15 HP FAN

1% BLOWDOWN - 5.7 GPM

2% MAKEUP - 11.5 GPM

ASSUME FAN OPERATES 20% OF THE TIME:

$$\text{ANNUAL FAN ENERGY} = \frac{15 \text{ HP} (0.8) (1152 \text{ H/yr})}{0.746 \text{ H/W}} = 18481 \text{ KWH/yr}$$

ASSUME PUMPING ENERGY FOR THE COOLING  
TOWER SYSTEM OFFSETS THE SAVINGS IN  
PUMPING ENERGY AT PUMP HOUSE.

J. Bouchillon, PE  
3/95  
1225 1 PCH  
- 10/95

# 1994 OUT-OF-POCKET COST FOR STEAM, B-200

GIVEN: 1994 AREA B MONTHLY USAGE & PROD. REPORT, BY KEN HARRIS

Sum of individual boilers steam output = 1,324,620,000 lbs

Building Steam Output = Sum - internal consumption (turbines, DA, etc)  
= 1,324,620,000 × .836 = 1,107,382,000 lbs  
= 1.107 m Btu  
16.4% (EEAD study, EMC Eng'g, 1992, p. C-4)

Steam Coal, 1994 = 64,673 tons

Btu content of coal = 64,673 tons × 2000 × 14,100  $\frac{\text{Btu}}{\text{lb}}$   
= 1.824 m m Btu  
(Per HOC coal purch spec June 1994)

Cost of treatment of Sulfuric System backwash water =  
50 gpm ave × 60  $\frac{\text{min}}{\text{hr}}$  × 8760 × \$.239  $\frac{\text{Utilities Cost Report}}{1000 \text{ gal}} = \$6,500/\text{yr.}$

COST of Filter Water for feed water =  
 $\frac{1,324,620,000 \text{ lbs} \times 0.148}{8 \text{ lbs water} \times 1000 \text{ gal}} = \$24,500/\text{yr}$   
Utilities Cost Report

Cost of electricity (motors, precipitators, etc) =  
412,000  $\frac{\text{KWH}}{\text{mo}} (\text{ave}) \times .035 \frac{\text{Utilities Cost Report}}{\text{KWH}} \times 12 \text{ mo} = \$173,000/\text{yr}$   
Cost str 2235, per mar '95 elec bill

Cost of fly ash disposal = 15,000 est

Cost of cinder removal = 10,000 est

[Cost of bldg maintenance = 393,391 routine + 529,110 Major = 922,465

COST of water treatment chemicals (See Basis Study JLB 1995) \$91,000

Out of Pocket Steam Cost = Coal + electricity + chemicals + FW + waste disposal + fly ash + cinder  
water softening

OPSC =  $\frac{\$2.91 \text{ million} + (\$45 \times 64,673) + \$173,000 + \$91,000 + \$24,500 + \$6,500 + 15,000 + 10,000}{1,107,382,000 \text{ lbs}}$   
Per Defense fuels, Geo. Tiffswirth 1/95

=  $\frac{3.23 \text{ million}}{1,107.} = 2.92 \frac{\$}{1000 \text{ lbs}}$   
3.75  $\frac{\$}{\text{Klbs}}$  Counting maintenance



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Calculations For:

ECO No. 4

REF. SHULLER 18" PIPE W/ 1" INSUL. & METAL JACKET

AIR PREHEATER

$$Q_{ATMOS} = \frac{2792(15 \text{ FT})}{1000} = 41.9 \text{ MBH @ } 1200^\circ \text{ OPER. TEMP}$$

TAILGAS HTR

$$Q_{ATMOS} = \frac{(1345 + 1978)(21 \text{ FT})}{2(1000)} = 34.9 \text{ MBH @ } 900^\circ$$

APPARENT PROD. GAS  $C_p$  FROM EXISTING SYST. CALCS:

$$C_p = \frac{5066.500 \text{ BTU}}{17644 \text{ H} (1470 - 1070)} = 0.434 \text{ B/H}^\circ\text{F}$$

NEW AIR PREHEATER LUG. PROD. GAS TEMP:

$$Q = 2086.1 \text{ MBH} + 41.9 \text{ MBH} = W C_p \Delta T = 17644 (0.434) (\Delta T)$$

$$\Delta T = 267.0$$

$$T_{LUG} = 1470 - 267.0 = 1203^\circ\text{F}$$

APPARENT PROD. GAS  $C_p$  @ TAILGAS HEATER FROM EXISTG. SYSTEM CALCS.

$$Q = W C_p \Delta T = 1895.4 (1000)$$

$$C_p = \frac{1895400}{17644 (1070 - 785)} = 0.377 \text{ B/H}^\circ\text{F}$$

ASSUME 800°F NEW T.G. HTR. LUG. PROD. GAS TEMP:

$$Q = \frac{17644 (0.377) (1203 - 800)}{1000} = 2680.7 \text{ MBH}$$

$$T.G. \Delta T = \frac{2680.7 / 1000}{1550 (0.24)} = 722^\circ\text{F} \quad T_{LUG} = 808^\circ\text{F}$$



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Calculations For:

ECO NO. 4

USING GAS TABLES FOR AIR @ LOW PRESS:

$$T_1 = 1265^\circ R$$

$$h_1 = 308 \text{ Btu/lb}$$

$$P_{r1} = 29.23$$

IDEAL CONDITIONS @ TURB EXH:

$$P_{r2} = P_{r1} \left( \frac{P_2}{P_1} \right) = 29.23 \left( \frac{14.7}{58+14.7} \right) = 5.91$$

$$T_{2, \text{IDEAL}} = 815^\circ R \rightarrow 355^\circ F$$

$$h_{2, \text{IDEAL}} = 195.5 \text{ Btu/lb}$$

$$EFF_{\text{TURB}} = 72.5\% \text{ FROM EARLIER CALCS}$$

$$HP = \frac{15450 \text{ Btu/hr} (308 \text{ Btu/lb} - 195.5 \text{ Btu/lb}) (0.725)}{2545} = 495$$

$$h_{\text{exh}} = h_1 - (h_1 - h_{2, \text{IDEAL}}) (0.725) = 226.4 \text{ Btu/lb}$$

$$T_{\text{EXH}} = 941^\circ R \text{ OR } 480^\circ F$$





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Calculations For:

TABLE 5

AMMONIA VAPORIZER, MIXER AND CONVERTER  
SAME AS TABLE 1.

AIR PREHEATER:

$$Q_{R\&T\&T\&A\&I\&R} = \text{SAME AS TABLE 1}$$

EXTRAPOLATED FROM SCHULER TABLE

$$Q_{R\&T\&A\&T\&M\&O\&S} = (3200)(15) = 45000 \text{ BTU/H}$$

$$T_{LUG} = T_{G\&I\&N} - \frac{Q_{A\&I\&R} + Q_{R\&T\&A\&T\&M\&O\&S}}{W C_P} = 1470 - \frac{2086056 + 45000}{17644(0.253)}$$

$$= 992.6^{\circ}\text{F}$$

$$\text{REVISED } Q_{R\&T\&A\&T\&M\&O\&S} = 2850(15) = 42750 \text{ BTU/H}$$

$$T_{LUG} = 1470 - \frac{2086056 + 42750}{17644(0.253)} = 993.1^{\circ}\text{F}$$

TAILGAS HEATER:

$$T_{T\&G\&O\&U\&T} = T_{T\&G\&I\&N} + \text{EFF}(T_{P\&G\&I\&N} - T_{T\&G\&I\&N}) = 85 + 0.711(993 - 85)$$

$$= 730.6^{\circ}\text{F}$$

$$Q_{R\&T\&T\&G} = W C_P \Delta T = 15450(0.248)(730.6 - 85) \\ = 2,473,635 \text{ BTU/H}$$

$$Q_{R\&T\&A\&T\&M\&O\&S} = 1100(21) = 23100 \text{ BTU/H}$$

$$T_{P\&G\&O\&U\&T} = T_{P\&G\&I\&N} - \frac{(Q_{R\&T\&T\&G} + Q_{R\&T\&A\&T\&M\&O\&S})}{W C_P} = 992.6 - \frac{(2473635 + 23100)}{17644(0.253)}$$

$$= 433.3^{\circ}\text{F}$$

$$\text{REVISED } Q_{R\&T\&A\&T\&M\&O\&S} = \left( \frac{85.4 + 134.5}{2} \right) 21 = 23090 \rightarrow T_{P\&G\&O\&U\&T} = 433.3^{\circ}\text{F}$$



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Calculations For:

TABLE 5

CASCADE COOLER:

$$Q_{REJ_{CAS}} = W_{DG} C_p \Delta T = 17092 (0.253) (433 - 105) \\ = 1,418,363 \text{ BTU H}$$

$$Q_{REJ_{CONDENS}} = \text{SAME AS TABLE 1} = 673700$$

ABSORPTION COLUMNS AND FINAL BLEACHER - SAME AS TABLE 1

TURBINE:

FROM KERNAN & KAYE @ 731°F (1191°R)  $P_{Y1} = 23.35$   $h_1 = 289.01$

$$P_{Y2} = P_{Y1} \left( \frac{P_2}{P_1} \right) = 23.35 \left( \frac{15}{73} \right) = 4.80$$

$$\text{THEOR. } h_2 = 184.72 \text{ B/}\#$$

$$h_2 = h_1 - \epsilon_{\text{TURB}} (h_1 - h_{2\text{THEOR}}) = 289.1 - .725 (289.1 - 184.7)$$

$$= 213.4$$

$$T_{\text{EXH}} = 889^\circ\text{R} \text{ OR } 429^\circ\text{F}$$

$$W K_{\text{TURB}} = \frac{W (\Delta h)}{2545} = \frac{15450 (289.01 - 213.4)}{2545} = 459 \text{ HP}$$

$$Q_{\text{REC}} = 459 (2545) = 1,168,175 \text{ BTU H}$$

$$Q_{\text{LOST}} = W C_p \Delta T = 15450 (0.248) (429 - 60) \\ = 1,413,860$$



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TABLE 5

$$T_{EXH} = \frac{W_{ST} C_{PST} T_{ST} + W_G C_{PG} T_G}{W_{ST} C_{PST} + W_G C_{PG}} = \frac{2000(0.5)(400) + 15450(0.248)(535)}{2000(0.5) + 15450(0.248)}$$

$$= 507^{\circ}F$$

$$W_{K_{TURB}} = \frac{W_{ST} C_{PST} \Delta T_{ST} + W_G C_{PG} \Delta T_G}{2545}$$

$$= \frac{2000(0.5)(731-400) + 15450(0.248)(731-535)}{2545}$$

$$= 425 \text{ HP}$$



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Calculations For:

ECO No. 5

## CURSORY EVALUATION :

REASONABLE ENERGY RECOVERY, IF IMPLEMENTED  
WITH ECO NO. 4, IS THE DIFFERENCE BETWEEN  
PREHEATER AND TAILGAS HEATERS LOSS TO  
ATMOSPHERE WITH & WITHOUT INSULATION

$$\text{PREHEATER: } 980.4 - 41.9 = 938.5 \text{ MBH}$$

$$\text{TAILGAS HTR: } 554.3 - 34.9 = 519.4 \text{ MBH}$$

$$\underline{1457.9 \text{ MBH}}$$

ECO NO. 4 HEAT REMOVAL REQ'D TO KEEP  
TAILGAS TO TURBINE BELOW 750°F MFR'S.  
MAX. TEMP.

$$Q = 15450(0.24)(805 - 745) = 222.5 \text{ MBH}$$

20 PSIG STEAM AVAILABLE @ STACK

$$Q = 15450(0.24)(480 - 275) = 760.1 \text{ MBH}$$



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Calculations For:

ECO No. 5

TURBINE OUTPUT

$$T_{IN} = 745^{\circ}F$$

$$P_{r1} = 24.38 \quad h_1 = 292.58$$

$$F_{T2} = \frac{14.7(24.38)}{72.7} = 4.93$$

$$h_2 = 185.7$$

$$h_{EXH} = 292.58 - (292.58 - 185.7)(.725) \\ = 215.09$$

$$T_{EXH} = 435^{\circ}F$$

$$HP = \frac{15450(292.58 - 215.09)}{2545} = 470.4$$



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Calculations For:

TABLE 6

AMMONIA VAPORIZER, MIXER, CONVERTOR, AIR PREHEATER,  
CASCADE COOLER AND TURBINE: SAME AS TABLE 5

RECOVERY BOILER:

SATURATION TEMP @ 30 PSIG - 275°F

USING COUNTERFLOW WASTE HEAT BOILER, ASSUME  
OUTLET GAS TEMP ( $T_{TGOUT}$ ) EQUALS 275°F

$$Q_{TG} = W C_p \Delta T = 15450 (0.248) (429 - 275) = 590066 \text{ BTU/H}$$

$$\text{STEAM} \rightarrow W = \frac{Q}{h_{ST} - h_{FW}} = \frac{590066}{1172.4 - 128.4} = 560 \text{ \#/HR}$$

$$Q_{LST} = W C_p \Delta T = 15450 (0.248) (275 - 60) = 823794$$

**Calculations For:**

ECO. NO. 6

### PROCESS DRY AIR RATIO:

$$m_d = m_w (1 - w) = 19350 \text{ #/HR} (1 - 0.0055) \text{ #/# DRY AIR}$$

$$= 19243.6 \text{ #/HR DRY AIR}$$

CONVERT MFG. DESIGN CONDENSATE RATE TO PROCESS DRY AIR RATE:

$$1^{\text{st}} \text{ STG CLR} = 216.4 \frac{(19243.6)}{27706} = 150^{\text{H}}/\text{HR}$$

$$2^{\text{nd}} \quad " \quad " = \frac{264.9(19243.6)}{27706} = 184^{\#}/\text{H.R}$$

$$\text{AFTER COOLER} = \frac{173 (19243.6)}{27445} = \frac{121 \#/\text{HR}}{455 \#/\text{HR}}$$

TURBINE ENTERING CONDITIONS:

$$\text{MASS FLOW} = 15450 + 1149 = 16599 \text{ \# / HR}$$

## SPRAY MIX PROCESS:

SPRAY MIX PROCESS:

$$Q = 1149 \frac{\text{lb}}{\text{hr}} [T_{\text{MIX}} - 207] + h_{\text{fg @ 25 PSIA}} (h_{\text{g @ } T_{\text{MIX}}} - 1181.0)$$

$T_{\text{MIX}}$	$h_{\text{g}}$	ERROR
325	1189.2	-147.9
400	1209.9	-232.3

$$Q = 15450 \text{ #/HR} (0.248 \text{ #/#}^\circ\text{F}) (435 - T_{\text{mix}}) \quad 316 \quad 1184.2 - 1317$$

$$T_{mix} = 4566 - 0.235 h_g$$

NOT ENOUGH HEAT IS AVAILABLE IN  
TAILGAS TO VAPORIZE THE CONDENSATE



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Calculations For:

ECO No. 6

EVALUATE FOR INCORPORATION W/ ECO No. 4

$$Q = 1149 \text{ #/HR} [(T_{\text{mix}} - 207) + 897.8 + h_g - 1181.0]$$

$$Q = 15450 (0.248) (805 - T_{\text{mix}})$$

$$T_{\text{mix}} = 953.8 - 0.235 h_g$$

<u>T<sub>MIX</sub></u>	<u>h<sub>g</sub></u>	<u>ERROR</u>
500°	1280.6	155.5
450°	1229.4	267.4
600°	1330.1	43.8
650°	1354.8	-12.0

USE 640°F TAILGAS/WATER VAPOR TEMP.  
@ TURBINE INLET.

$$h = \frac{15450 (0.26593) + 1149 (1340.0)}{16399} = 340.3 \text{ B/#}$$

$$P_{r1} = 17.413$$

$$s_1 = 1.81$$

$$P_{r2} = 17.413 \left( \frac{14.7}{72.0} \right) = 3.521$$

$$h_{2\text{IDEAL}} = 1188$$

$$T_{2\text{IDEAL}} = 244^\circ\text{F}$$

$$T_{2\text{IDEAL}} = 285^\circ\text{F}$$

RECALCULATE USING TURBINE EXHAUST HT.  
RECOVERY TO CONDENSATE





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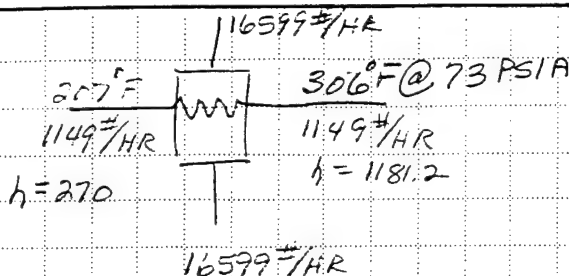
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Calculations For:

ECO No. 6



① ASSUME 100% PHASE CHANGE OF CONDENSATE, W/  
 TAILGAS TEMP. LVG. THE  $HX = 220^\circ F$

$$H_2O \text{ SIDE } Q_{HX} = 1149 \text{ \#/HR } (h_{LVG} - h_{ENT}) = 1149 (1181.2 - 270) = 104696.9$$

$$OIL \text{ SIDE } Q_{HX} = W_G C_{PG} \Delta T + W_S C_{PS} \Delta T = 15450 (0.24) \Delta T + 1149 (0.5) \Delta T$$

$$\Delta T = \frac{104696.9}{15450(0.24) + 1149(0.5)} = 244.5 \rightarrow T_{ENTIG} = 220 + 244.5 = 464.5$$

STEAM/TAILGAS MIXTURE CONDITIONS:

$$Q_{SET} = 1149 (h_{@MIX} - 1181.2)$$

$$Q_{OIL} = 15450 (0.24) (805 - T_{MIX})$$

$$T_{MIX} = 585.5 - 0.310 h_{@MIX}$$

$T_{MIX}$	$h_{MIX}$	ERROR
700	1380.2	-542
400	1231.6	-196
310	1183.8	-77.5

INSUFFICIENT HEAT IN TURBINE  
 EXHAUST GAS TO VAPORIZE  
 CONDENSATE



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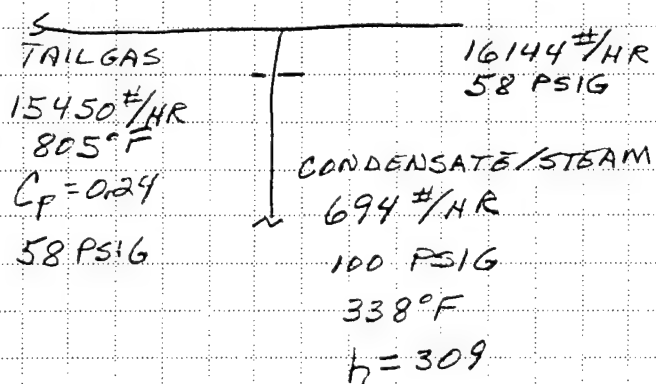
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Calculations For:

ECONO. 6

CONSIDER DELIVERING AMMONIA VAPORIZER  
CONDENSATE ONLY:

\* USE ORIFICE TRAP FOR CONTINUOUS DRAINAGE



$$15450(0.24)(805 - T_{mix}) = 694(h_{@mix} - 309)$$

$$T_{mix} = 862.8 - 0.187 h_{@mix}$$

$T_{mix}$	$h_{@mix}$	ERROR ( $T_{mix} - \text{CALL}$ )
750	1465	149.9
650	1355.5	40.7
540	1301.4	(79.4)
600	1330.9	(13.9)
615	1338.3	2.46



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Calculations For:

ECO No. 6

### TURBINE PROCESS:

#### GAS

$$P_{r1} = 16.005 \quad h_1 = 259.7$$

$$P_{r2} = \frac{14.7}{72.7} (16.005) = 3.236$$

$$T_2 = 227^\circ$$

$$h_2 = 164.5$$

$$h_{EXH} = 259.7 - (259.7 - 164.5)(.725) \\ = 190.68$$

$$T_{EXH} = 335^\circ$$

#### VAPOR

$$h_1 = 1338.3$$

$$s_1 = 1.80$$

$$h_2 = 1183$$

$$h_{EXH} = 1338.3 - (1338.3 - 1183)(.25) \\ = 1230.5$$

$$T_{EXH} = 380^\circ$$

$$HP = \frac{15450(.24)(615 - 335) + 694(1338.3 - 1230.5)}{2545}$$

$$= 437.3$$

THIS CONCEPT IS ABANDONED



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Calculations For:

ECO #7 ITERATION #1

WET GAS HEATER - 2000 #/HR STEAM + SPRAY  
STEAM SATURATION TEMPER.

$$15405(0.246)(T_{WG,IN} - 85) = 2000(0.50)(324 - T_{WG,IN})$$

$$T_{WG,IN} = \frac{2000(0.5)(324) + 15405(0.246)(85)}{15405(0.246) + 2000(0.5)} = 134.8^{\circ}\text{F}$$

$$C_{PWG} = \frac{2000(0.5) + 15405(0.246)}{17405} = 0.275^{\circ}\text{F}$$

$$T_{WG,OUT} = T_{WG,IN} + 0.711(T_{PG,IN} - T_{WG,IN}) = 134.8 + 0.711(993 - 134.8) = 745.0^{\circ}\text{F}$$

~~$$Q_{ATTEMPERATOR} = W_{WG} C_{PWG} (T_{WG,OUT} - 745) = 17405(0.275)(895.7 - 745) = 721307 \text{ BTU/H}$$~~

~~$$W_{ATTEMPERATOR} = \frac{Q_{ATTEMPERATOR}}{h_{fg}} = \frac{721307}{891.7} = 809 \text{ #/HR}$$~~

$$T_{PG,OUT} = T_{PG,IN} - \frac{W_{WG} C_{PWG} (T_{WG,OUT} - T_{WG,IN}) + Q_{ATTEMPERATOR}}{W_{PG} C_{PPG}}$$
$$= 1245 - \frac{17405(0.275)(895.7 - 134.8) + 721320}{17644(0.253)} = 227.5^{\circ}\text{F}$$

CONDENSATION WILL OCCUR AT 254°F  
IN PRODUCT GAS.

$$Q_{PG \text{ ECONOMIZER}} = 2000 \text{ #/HR} (1^{\circ}\text{F}) (240 - 150) = 180000 \text{ BTU/H}$$

$$W_{PG \text{ COND}} = \frac{Q_{PG \text{ ECON}}}{h_{fg16}} = \frac{180000}{944} = 191 \text{ #/HR}$$



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Calculations For:

### TURBINE

PARTIAL PRESSURE  $H_2O = .175(58 \text{ PSIG}) = 10.2 \text{ PSIG OR } 25 \text{ PSIA}$

$$S = 1.9764$$

$$h_{ST} = 1404.8$$

$$\text{THEOR. } h_{EXH_{ST}} = 1334 \text{ @ } 15 \text{ PSIA \& } 600^\circ$$

$$h_{EXH_{ST}} = h_{ST} - 0.725(h_{ST} - 1334) = 1404.8 - 0.725(1404.8 - 1334) \\ = 1353.5 \text{ B/H}$$

$$T_{EXH_{ST}} = 639^\circ \text{F}$$

GAS @  $745^\circ \text{F}$  :

$$P_{r1} = 24.38$$

$$h_{1,GAS} = 292.58 \text{ B/H}$$

$$P_{r2} = P_{r1} \left( \frac{P_2}{P_1} \right) = 24.38 \left( \frac{15}{73} \right) = 5.01$$

$$\text{THEOR. } h_{2,GAS} = 186.46 \text{ B/H}$$

$$h_{2,EXH_G} = 292.58 - 0.725(292.58 - 186.46) \\ = 215.64 \text{ B/H}$$

$$T_{2,EXH_G} = 437^\circ \text{F}$$

$$15405(0.246)(T_{EXH} - 437) = 2000(0.46)(639 - T_{EXH})$$

$$T_{EXH} = \frac{15405(0.246)(437) + 2000(0.46)(639)}{15405(0.246) + 2000(0.46)} = 476.5^\circ \text{F}$$



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Calculations For:

$$C_{PEXH} = \frac{W_{EXHG} C_{PEXHG} + W_{EXHST} C_{PEXST}}{W_{EXH}} = \frac{15405(0.246) + 2000(0.46)}{17405} = 0.271$$

$$W_{K_{TUX}} = \frac{W_{EXH} C_{PEXH} (745 - T_{EXH})}{2545}$$
$$= \frac{17405(0.271)(745 - 476.5)}{2545} = 497 \text{ HP}$$

WASTE HEAT BOILER

$$T_{STACK} = 250^{\circ}F - \text{ASSUMED}$$

$$Q_{BLR} = W_{EXH} C_{PEXH} (T_{EXH} - 250) = 17405(0.263)(492 - 250)$$
$$= 1061983 - \text{BTU/H}$$

$$W_{STEAM} = \frac{Q_{BLR}}{h_{fg}} = \frac{1061983}{891.7} = 1191 \text{ \# / HR}$$

TOTAL H<sub>2</sub>O ADDED TO TAILGAS:

~~809~~ #/HR  
1191 #/HR  
~~2000~~ #/HR - ASSUMED 2000 #/HR

PARTIAL PRESSURE OF H<sub>2</sub>O @ STACK:

$$P = 0.175(14.696) = 2.57 \text{ PSIA}$$

$$\text{DEW POINT} = 136^{\circ}F$$



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Calculations For:

ECO #7 ITERATION 2

CASE A 1800 #/HR SATURATED STEAM @ 80 PSIG INJECTED

WET GAS CONDITIONS:

$$W_{TG} C_{P_{TG}} (T_{WG} - 85) = W_{ST} C_{P_{ST}} (T_{SAT} - T_{WG})$$

$$[15405(0.248) + 1800(0.5)] T_{WG} = 1800(0.5)(324) + 15405(0.248)(85)$$

$$T_{WG} = 130.6^{\circ}\text{F}$$

$$C_{P_{WG}} = \frac{W_{TG} C_{P_{TG}} + W_{ST} C_{P_{ST}}}{W_{WG}} = \frac{15405(0.248) + 1800(0.5)}{17205} = 0.274 \text{ B/#}^{\circ}\text{F}$$

$$T_{WGOUT} = T_{WG} + EFF(T_{PGIN} - T_{WG}) = 130.6 + 0.71(993.1 - 130.6) = 743.8$$

$$T_{PGOUT} = T_{PGIN} - \frac{Q_{WG} + Q_{STEAM}}{W_{PG} C_{P_{PG}}} = 993.1 - \frac{17205(0.274)(743.8 - 130.6) + 41024}{17644(0.253)} = 336.3^{\circ}\text{F}$$

ECONOMIZER:

$$Q_{FW} = W_{FW} C_{P_{FW}} \Delta T_{FW} = 1800(1)(324 - 150) = 313200 \text{ BTU/H}$$

$$T_{PGOUT} = T_{PGIN} - \frac{Q_{FW}}{W_{PG} C_{P_{PG}}} = 336.3 - \frac{313200}{17644(0.253)} = 266.1^{\circ}\text{F}$$



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Calculations For:

TABLE 7

TURBINE:

PERCENT STEAM BY VOLUME:

$$MOL_{ST} = \frac{1800}{18.016} = 99.9$$

$$MOL_{TG} = 546.73$$

$$\% = \frac{99.9(100)}{546.73 + 99.9} = 15.45$$

$$INLET STEAM FRACTIONAL PRESSURE = 0.1545(58) = 8.96 \text{ SIG}$$

$$h_{ST,IN} = 1407.3 \quad S_{ST,IN} = 1.983$$

$$INLET STEAM FRACTIONAL PRESSURE = 0.1545(16) = 2.47 \text{ PSIA}$$

$$THEOR. h_{ST,OUT} = 1186.3 \quad S = 1.9815$$

$$h_{ST,OUT} = h_{ST,IN} - 225(1407.3 - 1186.3) = 1247.1$$

$$T_{ST,OUT} = 412^\circ\text{F}$$

$$INLET GAS FRACTIONAL PRESSURE = 58.91 = 49$$

$$P_{r1} = 24.31 \quad h_1 = 292.33 \rightarrow @ 744^\circ\text{F}$$

$$\text{THEORETICAL } P_{r2} = P_{r1} \left( \frac{P_2}{P_1} \right) = 24.31 \left( \frac{16}{63.7} \right) = 5.93$$

$$\text{THEOR. } h_2 = 195.71$$

$$h_2 = 292.33 - 0.725(292.33 - 195.71) = 222.28$$

$$T_2 = 925^\circ\text{R OR } 465^\circ\text{F}$$





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TABLE 7

$$W_{ST} C_{P,ST} (T_{EXH} - T_{STOUT}) = W_{GAS} C_{P,GAS} (T_2 - T_{EXH})$$

$$[1800(0.47) + 15405(0.242)] T_{EXH} = 15405(0.242)(465) + 1800(0.47)(412)$$

$$T_{EXH} = 455.4^{\circ}F$$

$$h_{INLET} = \frac{W_{ST} h_{ST,IN} + W_G h_G}{W_{ST} + W_G} = \frac{1800(1407.3) + 15405(292.33)}{1800 + 15405}$$
$$= 409.0 \text{ Btu/lb}$$

$$h_{EXH2} = \frac{W_{ST} h_{ST,OUT} + W_G h_G}{W_{ST} + W_G} = \frac{1800(1247.1) + 15405(222.28)}{1800 + 15405}$$

$$h_{EXH} = 329.5 \text{ Btu/lb}$$

$$W K_{TURB} = \frac{(17205)(409.0 - 329.5)}{2545} = 537.4 \text{ HP}$$

$$Q_{REL} = 537.4(2545) = 1,367,798 \text{ Btu/hr @ TURBINE}$$

$$Q_{REF} = W C_p \Delta T = 17205(0.274)(455.4 - 60) = 1,863,983 \text{ Btu/hr}$$

WASTE HEAT BOILER:

$$Q = W_{ST} h_{fg} = 1800(891.7) = 1,605,060 \text{ Btu/hr}$$

$$T_{STACK} = T_{EXH} - \frac{Q}{W_{EXH} C_{P,EXH}} = 455.4 - \frac{1605060}{17205(0.274)} = 115^{\circ}F$$



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Calculations For:

ECO #1 ITERATION 3

CASE B 1500 #/HR SATURATED STEAM @ 80 PSIG INJECTED

SUBSTITUTION OF 1500 #/HR IN FORMULAS OF CASE C GIVES THE FOLLOWING RESULTS:

WET GAS CONDITIONS:

$$T_{WG} = 124.2^{\circ}\text{F}$$

$$C_{P_{WG}} = 0.270 \text{ Btu/lb}^{\circ}\text{F}$$

$$T_{WG_{OUT}} = 742.0^{\circ}\text{F}$$

$$T_{PG_{OUT}} = 352.2^{\circ}\text{F}$$

ECONOMIZER:

ALLOW OUTLET OF ECONOMIZER TO CONTAIN SMALL PERCENTAGE OF STEAM SUCH THAT  $T_{PG_{OUT}} = 265^{\circ}\text{F}$

$$Q_{FW} = W_{FW} \Delta h_{FW} = W_{PG} C_{P_{PG}} \Delta T_{PG}$$

$$\Delta h_{FW} = \frac{17644(0.253)(352.2 - 265)}{1500} = 259.5^{\circ}\text{Btu/lb}$$

$$Q_{FW_{SENS}} = W_{FW} C_{P_{FW}} \Delta T = 1500(1)(324 - 150) = 261000 \text{ Btu/h}$$

FW EQUILIBRIUM:

$$W_{STEAM} = \frac{W_{FW} \Delta h_{FW} - Q_{FW_{SENS}}}{h_{fg}} = \frac{1500(259.5) - 261000}{891.7} = 143.8 \text{ #/HR}$$

$$Q_{REC} = W_{FW} \Delta h_{FW} = 1500(259.5) = 389250 \text{ Btu/h}$$

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Calculations For:

**TURBINE:**

$$MOL_{ST} = 83.26$$

$$MOL_{TG} = 546.73$$

$$y_o = 13.22$$

$$PARTIAL PR = .1322(58) = 7.67 \text{ PSIG} \rightarrow 22.37 \text{ PSIA INLET}$$

$$h_{STIN} = 1403.4 @ 742^\circ F \quad S_{STIN} = 1.985$$

$$PARTIAL PR = .1322(16) = 2.11 \text{ PSIA}$$

$$THEOR h_{STOUT} = 1159 \quad S = 1.985$$

$$h_{STOUT} = 1403.4 - .725(1403.4 - 1159) = 1226.2$$

$$T_{STOUT} = 367^\circ F$$

$$GAS PARTIAL PR = 58 - 7.67 = 50.3 \text{ PSIG OR } 65.0 \text{ PSIA}$$

$$PR_1 = 24.16 \quad h_1 = 291.81 \rightarrow @ 742^\circ F$$

$$PR_2 = 24.16 \left( \frac{16}{65} \right) = 5.95$$

$$THEOR h_2 = 195.9$$

$$h_2 = 291.81 - 0.725(291.81 - 195.9) = 222.28 \text{ Btu/lb}$$

$$T_2 = 465^\circ F$$

$$h_{EXH} = 311.4 \text{ Btu/lb}$$

$$T_{EXH} = 449.7$$

$$W_{KTURB} = 525 \text{ HP}$$

$$h_{INLET} = 390.4$$



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Calculations For:

WASTE HEAT BOILER:

$$Q = (W_{ET} - W_{STACK}) h_{fg} = (1500 - 143)(891.7) = 1210037 \text{ BTU/H}$$

$$T_{STACK} = T_{EXH} - \frac{Q}{W_{EXH} C_{P_{EXH}}} = 449.7 - \frac{1210037}{16905(0.275)} = 189.4^{\circ}\text{F}$$



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Calculations For:

ECO #7 - ITERATION 4

CASE C 1400#/HR STEAM @ 80 PSIG INJECTED @ TAIL GAS  
& WITH PRODUCT GAS LEAVING THE  
HEAT RECOVERY UNIT AT 245°F

WET GAS CONDITIONS:

$$W_{TG} C_{PTG} (T_{WG} - 85) = W_{ST} C_{PST} (T_{SAT} - T_{WG})$$

$$[15405(0.248) + 1400(0.47)] T_{WG} = 1400(0.47)(324) + 15405(0.248)(85)$$

$$T_{WG} = 120.1^\circ F$$

$$C_{PWG} = \frac{W_{TG} C_{PTG} + W_{ST} C_{PST}}{W_{TG} + W_{ST}} = \frac{15405(0.248) + 1400(0.47)}{15405 + 1400} = 0.266 \text{ B}/\text{#}^\circ F$$

$$T_{WG,OUT} = T_{WG} + EFF(T_{PGIN} - T_{WG}) = 120.1 + 0.711(993.1 - 120.1) = 740.8^\circ F$$

$$T_{PG,OUT} = T_{PGIN} - \frac{Q_{WG} + Q_{REINJECTION}}{W_{PG} C_{PPG}} = \frac{(15405 + 1400)(0.266)(740.8 - 120.1) + 41000}{17644(0.253)} = 993.1 - 630.8 = 362.3^\circ F$$

ECONOMIZER:

$$Q_{FW} = W_{PG} C_{PPG} \Delta T_{PG} = 17644(0.253)(362.3 - 245) = 523619$$

$$\Delta h_{FW} = \frac{523619}{1400} = 374.0 \text{ B}/\text{#}$$

$$Q_{FW,SENS} = W_{FW} C_{PFW} \Delta T_{FW} = 1400(1)(324 - 85) = 243600 \text{ BTU/H}$$

$$W_{STEC} = \frac{W_{FW} \Delta h_{FW} - Q_{FW,SENS}}{h_{fg}} = \frac{1400(374.0) - 243600}{891.7} = 314 \text{ #/HR}$$



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Calculations For:

TURBINE :

$$MOL_{ST} = \frac{1400}{18.016} = 77.7$$

$$MOL_{T_0} = 546.73$$

$$\% = \frac{77.7}{546.73 + 77.7} = 12.44$$

$$INLET \text{ STEAM PARTIAL PRESSURE} = .1244(58) = 7.22 \text{ PSIG}$$

$$h_{STIN} = 1402.9$$

$$S_{STIN} = 1.9889$$

$$OUTLET \text{ STEAM PARTIAL PRESSURE} = .1244(16) = 1.99 \text{ PSIA}$$

$$THEOR. h_{STOUT} = 1151.4 \text{ Btu/lb}$$

$$h_{STOUT} = h_{STIN} - 0.725(h_{STIN} - 1151.4) = 1402.9 - .725(1402.9 - 1151.4) \\ = 1220.5 \text{ Btu/lb}$$

$$T_{STOUT} = 354.3^\circ\text{F}$$

$$INLET \text{ GAS PARTIAL PRESS.} = (58 - 7.22) = 50.78 \text{ PSIG @ } 741^\circ\text{F} \\ \text{OR } 1201^\circ\text{R}$$

$$P_{r1} = 24.08$$

$$h_1 = 291.56$$

$$P_{r2} = P_{r1} \left( \frac{16}{50.78} \right) = 7.59$$

$$THEOR. h_2 = 210$$

$$h_2 = h_1 - EFF(h_1 - 210) = 291.56 - .725(291.56 - 210) \\ = 232.4$$

$$T_2 = 506^\circ\text{F}$$



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Calculations For:

$$W_s C_{PST} (T_{EXH} - T_{STOUT}) = W_{GAS} C_{PGAS} (T_2 - T_{EXH})$$

$$[1400(0.47) + 15405(0.248)] T_{EXH} = 15405(0.248)(506) + 1400(0.47)(354)$$

$$T_{EXH} = 483.7^{\circ}F$$

$$h_{INLET} = \frac{W_{ST} h_{STIN} + W_G h_1}{W_{ST} + W_G} = \frac{1400(1402.9) + 15405(291.56)}{1400 + 15405}$$
$$= 384.1 \text{ B/\#}$$

$$h_{EXH} = \frac{W_{ST} h_{STOUT} + W_G h_2}{W_{ST} + W_G} = \frac{1400(1220.5) + 15405(232.4)}{1400 + 15405}$$
$$= 314.7 \text{ B/\#}$$

$$W_{KTURN} = \frac{(1400 + 15405)(384.1 - 314.7)}{2545} = 458 \text{ HP}$$

$$Q_{RSC} = 458(2545) = 1165979 \text{ BTU/H}$$

WASTE HEAT BOILER:

$$Q = (W_{ST} - W_{STECON}) h_{fg} = (1400 - 314)(891.7) = 968386 \text{ BTU/H}$$

$$T_{STACK} = T_{EXH} - \frac{Q}{W_{WB} C_{PW6}} = 483.7 - \frac{968386}{16805(0.266)}$$
$$= 267.1^{\circ}F$$



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Calculations For:

ECO #7 ITERATION 5

FINAL CASE: STEAM & SPRAY WATER INJECTED @ TAIL GAS  
LEAVING TAIL GAS HEATER & WITH  
WASTE HEAT BOILERS IN BOTH  
TURBINE EXH. GAS & PRODUCT GAS LOG  
TAIL GAS HEATER

WET GAS CONDITIONS: (USING ECO #4 RESULTS)

$$W_{TG} C_{PTG} (T_{TG} - T_{WG}) = W_{ST} C_{PST} (T_{WG} - T_{SAT})$$

$$[15405(0.248) + 1500(0.47)] T_{WG} = 1500(0.47)(324) + 15405(0.248)(731)$$

$$T_{WG} = \frac{667.6}{888.8}^{\circ}\text{F}$$

~~ATOMOSPHERIC SPRAY:~~

MFRS TURBINE INLET  
MAXIMUM MINUS 5°F

$$Q_{AT} = W_{WG} C_{PWG} (T_{WG} - 745) = (15405 + 1500)(0.270)(888.8 - 745)$$
$$= 656259 \text{ BTU/H}$$

$$W_{AT} = \frac{Q_{AT}}{h_{fg}} = \frac{656259}{891.9} = 736 \text{ \#/HR}$$

PRODUCT GAS WASTE HEAT BOILER:

\* WITH 150°F FEEDWATER, ASSUME PRODUCT GAS  
LEAVING BOILER @ 225°F

$$Q_{REC} = W_{PG} C_{PPG} (T_{PGOUT} - 225) = 17644(0.253)(433 - 225)$$
$$= 816900$$
$$= 928498 \text{ W.O. CONSIDERING CONDENSATION}$$

$$W_{STPG} = \frac{Q_{REC}}{C_{PFO} \Delta T_{FW} + h_{fg}} = \frac{928498}{(1)(324 - 150) + 891.7} = 871 \text{ \#/HR}$$

766





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Calculations For:

TURBINE:

$$MOL_{H_2O} = \frac{1500 + 736}{18.016} = \frac{83.3}{124.1}$$

$$MOL_{TG} = 546.73$$

$$\% = \frac{124.1 + 83.3}{546.73 + 124.1} = \frac{13.2}{18.5}$$

$$STEAM \text{ PARTIAL PRESSURE} = 0.185(58) = 10.73 \text{ PSIG INLET}$$
$$= 0.185(16) = 2.96 \text{ PSIA OUTLET}$$

$$h_{STIN} = 1404.8 \text{ Btu/lb} @ 745^\circ F \quad S_{STIN} = 1.974$$

$$THEOR. h_{STOUT} = 1180.7 \text{ Btu/lb}$$

$$h_{STOUT} = h_{STIN} - EFF(h_{STIN} - 1180.7) = 1404.8 - 0.725(1404.8 - 1180.7)$$
$$= 1242.3 \text{ Btu/lb}$$

$$T_{STOUT} = 402^\circ F$$

TAIL GAS:

$$P_{T1} = 24.38 @ 1205^\circ R \quad h_{T1} = 292.58$$

$$P_{T2} = P_{T1} \left( \frac{16}{70} \right) = 5.57$$

$$THEOR. h_2 = 192.30$$

$$h_2 = h_{T1} - EFF(h_{T1} - 192.3) = 292.58 - 0.725(292.58 - 192.3)$$
$$= 219.9 \text{ Btu/lb} \quad T_{TOUT} = 455^\circ F$$

$$W_{KTURB} = \frac{W_{ST} \Delta h_{ST} + W_G \Delta h_G}{2545} = \frac{1500(1404.8 - 1242.8) + 15405(292.58 - 219.9)}{2545}$$
$$= 535$$
$$= 582 \text{ HP}$$



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Calculations For:

## TURBINE EXHAUST WASTE HEAT BOILER

$$W_{ST} = \frac{W_{STPG} C_{PST} (T_{STOUT} - 225) + W_{TG} C_{PTG} (T_{TGOUT} - 225) - W_{AT} C_{PAT} (324 - 150)}{C_{PFW} \Delta T_{FW} + h_{fg}}$$
$$= \frac{766 (0.47) (402 - 225) + 15405 (0.248) (455 - 225) - 736 (114)}{(324 - 150) + 891.7}$$
$$= 845 \# / HR$$

$$TOTAL \text{ STEAM} = 766 + 845 = 1611 \# / HR$$

$$\frac{W_{ST} \text{ ASSUMED}}{1716} = \frac{\Delta T_{REG}}{440 - 225}$$

$$440 - T_{LVG} = \frac{1500 (440 - 225)}{1716}$$

$T_{LVG} = 252^{\circ} F \leftarrow$  USE THIS FOR RECOVERY  
BOILER CUTLET TEMP.

$$W_{ST} C_{PST} (T_{EXH} - 402) = W_{TG} C_{PTG} (455 - T_{EXH})$$

$$T_{EXH} = 446^{\circ} F$$

$$Q_{LOST} = W_{EXH} C_{PEXH} \Delta T_{STK} = 16905 (0.275) (250 - 60)$$
$$= 921690$$

$$Q_{REG} = W_{EXH} C_{PEXH} (T_{EXH} - T_{STK}) = 16905 (0.275) (446 - 60) = 1794466$$



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Calculations For:

ECO #7A

$$W_{ST} = 1200 \text{ \#/HR} - \text{CLAYTON QUOTATION}$$

$$\frac{T_{WG2} - T_{WG1}}{T_{PG1} - T_{WG1}} = 0.711$$

$$T_{WG2} = T_{WG1} + 0.711(T_{PG1} - T_{WG1})$$

$$W_{ST} C_{PST} (T_{ST} - T_{WG}) = W_{TG} C_{PTG} (T_{WG} - T_{TG})$$

$$1200(0.47)(324 - T_{WG}) = 15405(0.248)(T_{WG} - 85)$$

$$T_{WG1} = \frac{15405(0.248)(85) + 1200(0.47)(324)}{15405(0.248) + 1200(0.47)} = 115.7^{\circ}\text{F}$$

$$T_{WG2} = 115.7 + 0.711(993 - 115.7) = 739.5^{\circ}\text{F}$$

$$T_{PG2} = T_{PG1} - \frac{Q_{RECOV}}{W_{PG} C_{PPG}} = 993 - \frac{(15405 + 1200)(0.275)(739.5 - 115.7)}{17644(0.258)}$$
$$= 367.3^{\circ}\text{F}$$

TURBINE:

WG. CONSTITUENT	# MOLES/HR
N <sub>2</sub>	505.16
A	6.21
NO	30.62
H <sub>2</sub> O	$4.74 + \frac{1200}{18.016} = 71.35$
	<hr/> 613.34

$$\text{H}_2\text{O} \% \text{ BY VOL} = \frac{71.35(100)}{613.34} = 11.6$$



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Calculations For:

$$H_2O \text{ PARTIAL PRESS} = (58 + 14.7)(.116) = 8.43 \text{ PSIA}$$

$$h_g = 1403.5 \text{ @ } 739.5^\circ\text{F}$$

$$S_g = 2.0667$$

$$\text{THEOR } h_2 = 1255.4$$

$$h_2 = 1255.4 - .725(1403.5 - 1255.4) = 1296.1 \quad T_{EYH} = 517^\circ\text{F}$$

$$P_{F1} = 23.94 \quad h_{G1} = 291.05$$

$$P_{F2} = P_{F1} \left( \frac{15}{64.3} \right) = 5.58$$

$$\text{THEOR } h_2 = 192.3$$

$$h_{WG2} = 291.05 - .725(291.05 - 192.3) = 211.34$$

$$T_{WG2} = 420^\circ\text{F}$$

$$W_{KTB} = \frac{1200(1403.5 - 1296.1) + 15405(291.05 - 211.34)}{2545}$$

$$= 533 \text{ HP}$$

$$1200(.47)(517 - T_{WG2}) = 15405(.275)(T_{WG2} - 420)$$

$$T_{WG2} = 432^\circ\text{F}$$



63°F LESS THAN BASIS FOR  
CLAYTON QUOTATION

ASSUME SYSTEM W.O. PR. GAS RECOVER w/  
STEAM INJECTED IN TAILGAS @ OUTLET OF  
ABSORPTION COLUMN WILL PRODUCE 525 HP.



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Calculations For:

TURBINE INLET/OUTLET PIPING.

WET GAS LEAVING HEATER:

16905  
~~17405~~ #/HR @ 745°F

DRY GAS = 15320 #/HR

H<sub>2</sub>O VAPOR = <sup>1500</sup>  
~~2085~~ #/HR

CONSTITUENTS	# MOLES/HR	% BY VOLUME
DRY GAS	<sup>1500</sup> 541.99	82.9% 86.7
H <sub>2</sub> O	<sup>2505</sup> 18.015 = 145.74 83.26	17.6% 13.3

657.73

625.25

133

7.7

H<sub>2</sub>O PARTIAL PRESSURE = 0.176(58) = 10.2 PSIG

$$V_{DG} = \frac{P_{ATM} V_{ATM} (T_{OG})}{T_{ATM} (P_{OG})} = \frac{14.7(13.07) \left( \frac{455+460}{17} \right)}{518.7(58-70.2+14.7)} = \frac{5.21}{7.14} \text{ FT}^3/\#$$

V<sub>H<sub>2</sub>O</sub> = 28.64 FT<sup>3</sup>/# FROM KEENAN & KEYES

$$V_{WG} = \frac{15320 \left( \frac{5.21}{7.14} \right) + 2085 \left( \frac{18.38}{28.64} \right)}{\frac{17405}{16905}} = \frac{6.35}{9.72} \text{ FT}^3/\#$$

$$VELOCITY = \frac{16905 \text{ #/HR} \left( \frac{6.35}{9.72} \text{ FT}^3/\# \right) \left( 144 \frac{\text{IN}^2}{\text{FT}^2} \right)}{60 \text{ MIN/HR} (31.7 \text{ IN}^2)} = \frac{8089}{12804} \text{ FPM}$$

$$N_{RE} = \frac{V D \rho}{\mu} = \frac{8089 (12804 \text{ FT/MIN}) (6.357 \text{ IN}) (0.07651 \text{ #/FT}^3)}{(218 \times 10^{-7} \text{ #/SEC-FT}) (60 \text{ SEC/MIN}) (12 \text{ IN/FT})}$$

$$= 396759 \text{ } 250648$$

$$\Delta P = \frac{3.4 \times 10^{-6} F L W^2}{d^5} = \frac{(3.4 \times 10^{-6}) (0.018) (100) (17405)^2 (9.72)}{(6.357)^5}$$

$$= 1.5 \text{ PSI}$$



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12-12-95  
Date:

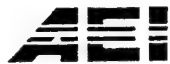
Job No:  
95094-00  
Sheet No:  
\_\_\_\_\_ of \_\_\_\_\_

Calculations For:

### TURBINE EXHAUST VELOCITY

$$V_2 = \frac{(72.7 \text{ PSIA}) \left( \frac{6.35}{145+460} \right) (952^\circ \text{F})}{(1205^\circ \text{F}) (15.3 \text{ PSIA})} = \frac{22.68}{36.49} \text{ FT}^3/\#$$

$$\text{VELOCITY} = \frac{16905 \text{ \#}/\text{HR} \left( \frac{22.68}{36.49} \text{ FT}^3/\# \right) (144 \text{ IN}^2/\text{FT}^2)}{60 \text{ \#}/\text{HR} (111.93 \text{ IN}^2)} = \frac{8220}{13,618} \text{ FPM}$$



AFFILIATED ENGINEERS SE, INC.  
3300 SW Archer Road  
Gainesville, Florida 32608  
(904) 376-5500  
FAX (904) 375-3479

Made By:

PDL

Date:

11-14-95

Job No:

95094-00

Checked By:

Date:

Sheet No:

of

Calculations For:

ECO SAVINGS

No. 1

# 266543

$$\text{OPERATING HOURS PER YEAR} = 4 \text{ %} (24 \text{ %}) (12 \text{ %}) = 1152$$

$$\text{ELECT. SAVINGS} = 2.0182 \times 10^6 \text{ BTU} (1152 \text{ %}) = 2324.97 \text{ M. BTU/YR}$$

$$\text{STEAM INCREASE} = 12.7855 \times 10^6 \text{ BTU} (1152 \text{ %}) = 10537.79 \text{ %}$$

$$\text{DEMAND} = 793 (.748) = 593.16 \text{ KW} \rightarrow \$13050$$

No. 2

# 192277

$$\text{ELECT. INCREASE} = \frac{(2786.8 - 2018.2)(1152)}{1000} = 885.427 \text{ %}$$

$$\text{STEAM OFFSET} = \frac{2990.8 - 1152}{1000} = 3445.402 \text{ %}$$

$$\text{DEMAND} = -302 (.748) = -225.90 \rightarrow -4970$$

No. 3

# 31200

No. 4 # 4850

$$\text{ELECT. SAVINGS} = \frac{(2018.2 - 1618.6)(1152)}{1000} = 460.339 \text{ %}$$

$$\text{DEMAND} = (793 - 636)(.748) = 117.44 \rightarrow \$2585$$

$$\text{No. 5} \quad \$27000 + \$4850 = \$31850$$

$$\text{ELECT. SAVINGS} = (2018.2 - 1618.6)(1152) = 460.339$$

$$\text{STEAM OFFSET} = \frac{560}{694} (714.1)(1152) = 663.804$$

$$\text{STEAM PLANT MAKEUP} = (694 - 560)(1152) = 154368 \text{ #/YR}$$

# 4850  
COST-4850



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Date:

Job No:

Checked By:

Date:

Sheet No:

of

Calculations For:

No. 7

$$\text{ELECT SAVINGS} = (2018.2 - 1425.2) \frac{(1152)}{1000} = 683.136$$

$$\text{ADDTL. STEAM PLANT MAKEUP} = 420 \text{ #/HR} (1152) = 483840 \text{ #/YR}$$

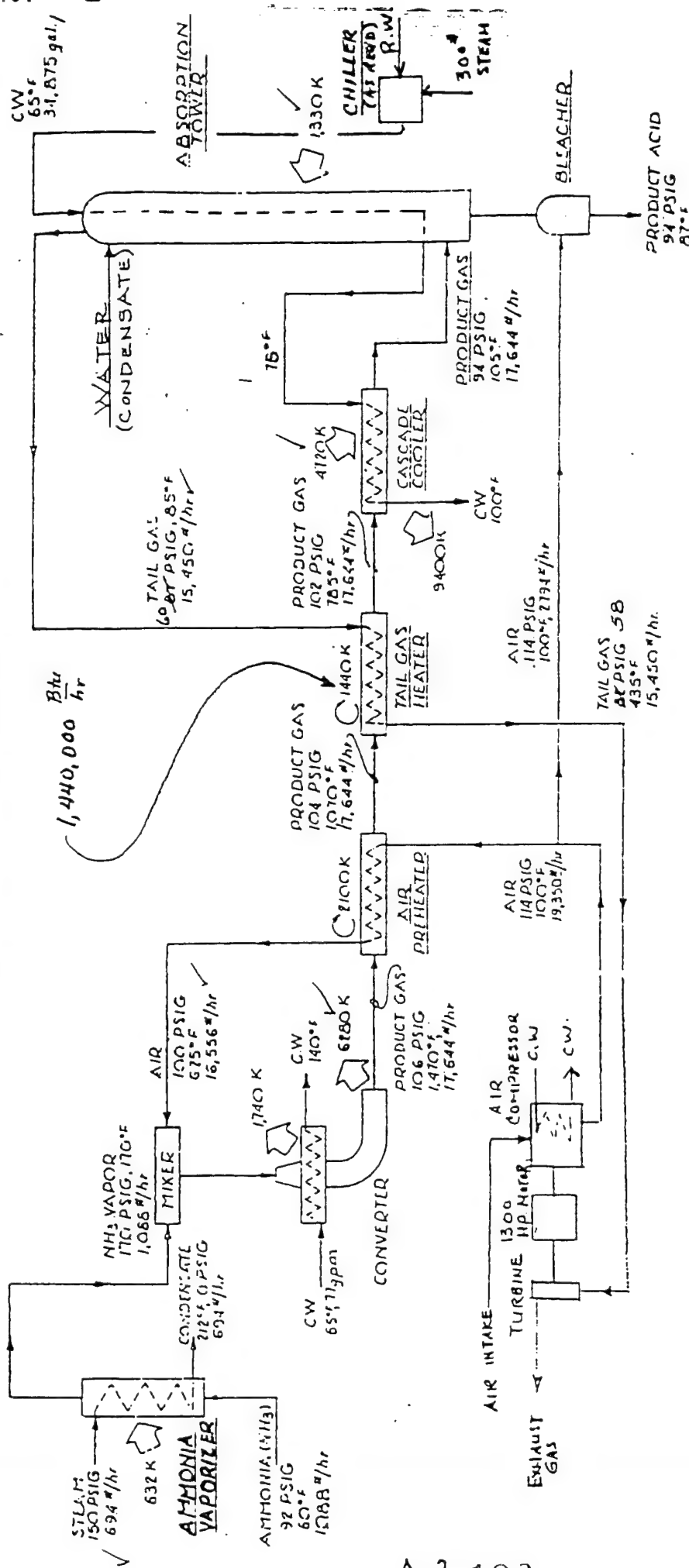
# 412 ANNUAL RECURRING EXP.

$$\text{DEMAND} = (793 - 560) \cdot 748 = 174.28 \rightarrow \$3835$$



**REFERENCE  
MATERIAL**

# ENERGY BALANCE-BLDG. 302-B NITRIC ACID MANUFACTURING



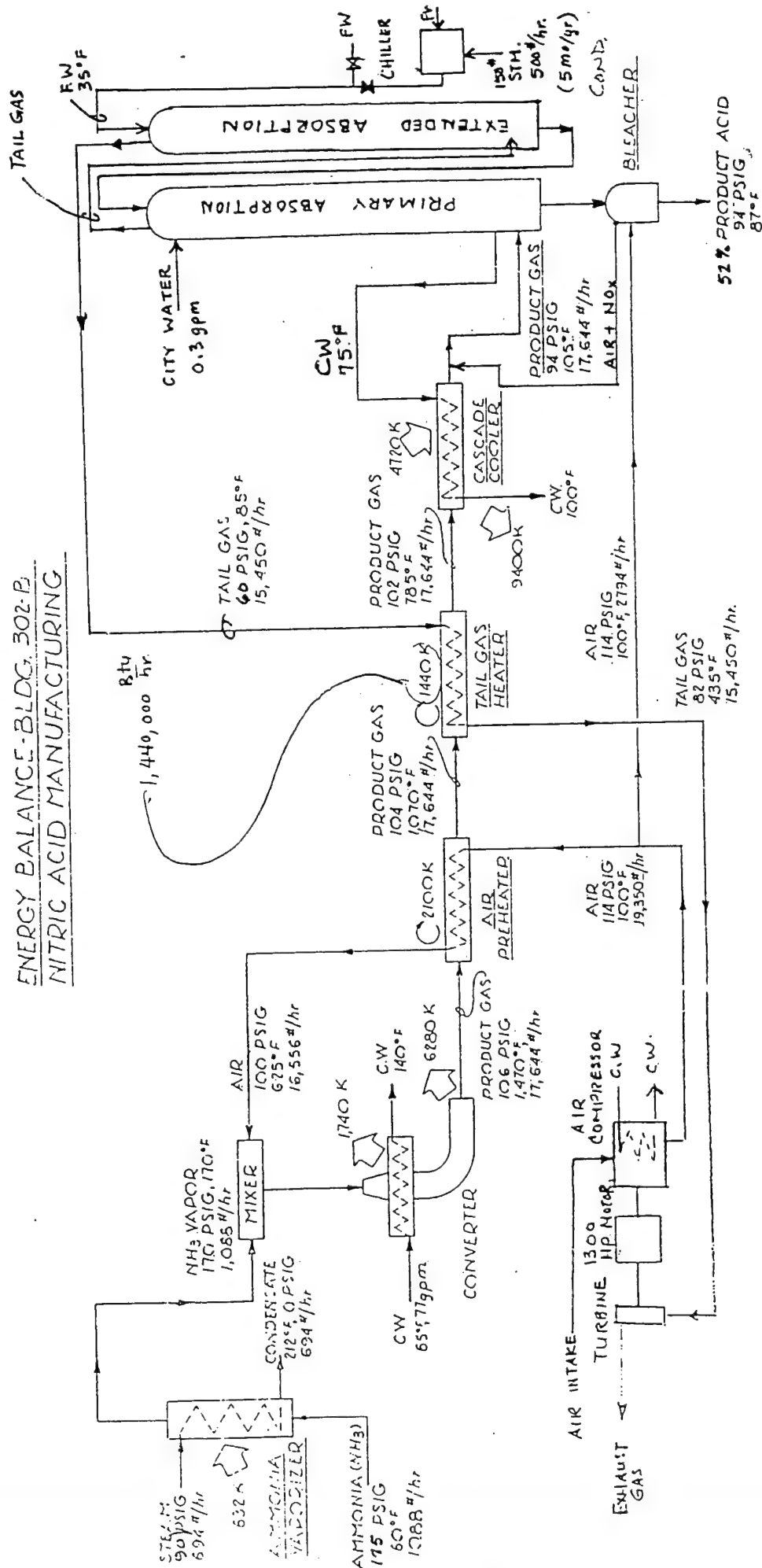
AS BUILT JAN 1995

HOLSTON ARMY AMMUNITION PLANT  
HOLSTON DEFENSE CORPORATION  
KINGSPORT, TENN.  
BLDG. 302-B, NITRIC ACID MFG.

DRAWN-PB  
DATE-9-14-76  
APP'D-10/86  
SK-2286

FIGURE 16

# ENERGY BALANCE-BLDG. 302-B NITRIC ACID MANUFACTURING



AS-BUILT APRIL 1995 *J. Brudillon*

HOLSTON ARMY AMMUNITION PLANT  
HOLSTON DEFENSE CORPORATION  
KINGSPORT, TENN.  
BLDG. 302-B, NITRIC ACID MFG.

DRAWN-P  
DATE: 2-14-  
APP'D: 108  
SK# 2286

55 TPD UNIT  
FIGURE 16

HOLSTON ARMY AMMUNITION PLANT  
PROCESS ENERGY INVENTORY  
NITRIC ACID MANUFACTURING, BUILDING 302-B

Equipment	Heat Added		Heat Recovered		Heat Removed		Heat Lost		Comments
	1000 Btu/hr	Source	1000 Btu/hr	Donor	1000 Btu/hr	Source	1000 Btu/hr	Source	
Ammonia Vaporizer	631.9	Steam	694				69.4		Basis: 45 TPD production. .2 gpm
Converter	6380	Reaction		Ammonia	1,740	R.W.	77.5		
PRE-Compressor	1536	Elect.		Air	2100	Product	307	Machine	Mechanical & electrical losses
				Product		Gas		Exhaust Gas	
YRD-Compressor				Tail Gas	1082	Air	60		318.8 hp-hr/hr 75% turbine efficiency.
Air Preheater									*Pounds per hour.
Tail Gas Heater									
Cascade Cooler	4733	Reaction	17,644						
Absorption Tower	1331	Reaction	16.3						
Bleacher									
Total Process Energy	18,273	Added or Recovered							

Imbalance = 2X  
Kingsport, Tennessee

TABLE 28

EMC ENGINEERS, INC.  
PROJ. # \_\_\_\_\_ PROJECT \_\_\_\_\_  
SHEET NO. \_\_\_\_\_ OF 102  
CALCULATED BY \_\_\_\_\_ DATE \_\_\_\_\_  
CHECKED BY \_\_\_\_\_ DATE \_\_\_\_\_  
SUBJECT \_\_\_\_\_

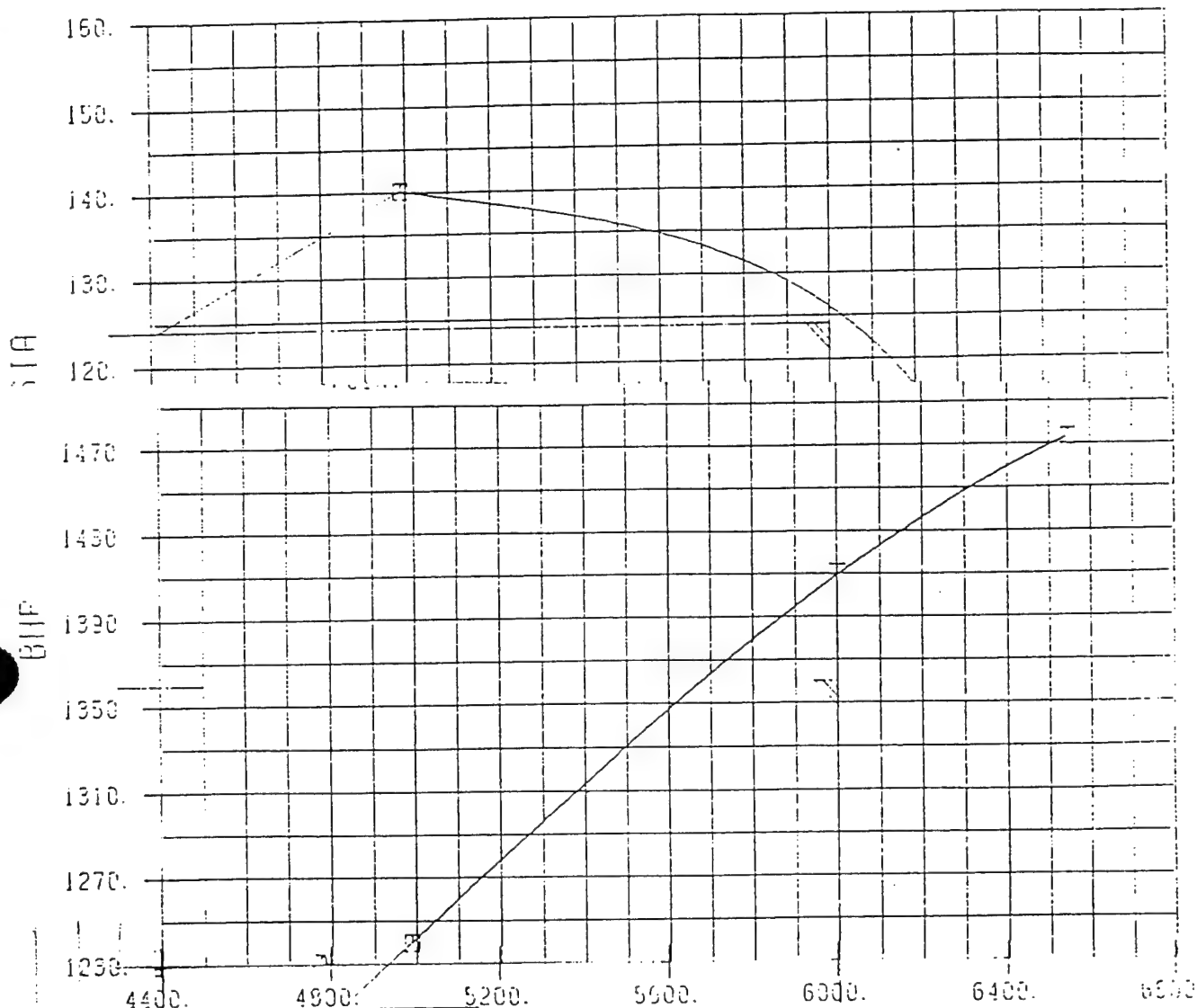
# JOY MANUFACTURING CO. BUFFALO N. Y.

TEST PERFORMANCE F07693M1 CUSTOMER WITNESS TEST

HOLSTEN DEFENSE CORP

14705Z

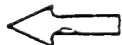
\*7693\*



SCFM (avg) 14.70 60 0

1150

1110



USE 1095 HP

1070

4000

vapor pressures ( $p$ , psia) at various temperatures ( $t$ , deg F) are as follows:

$t$	200	250	300	350	400	450	500
$p$	0.060	0.227	0.701	1.832	4.117	8.638	16.29

$t$	550	600	650	700	750	800
$p$	28.54	47.01	73.55	110.1	158.6	221.0

Dowtherm A is the eutectic mixture of diphenyl oxide and diphenyl containing 73.5 percent of diphenyl oxide and 26.5 percent of diphenyl and melting at 53.6°F. It is used as a liquid heating medium at elevated temperatures. Its low vapor pressure permits high temperature without attendant high pres-

ures. Table 32 (Badger, *Ind. Eng. Chem.*, Sept., 1937) gives properties of this eutectic.

**Pure Hydrocarbons** The vapor pressures of various commercially important pure hydrocarbons are shown graphically in Fig. 25.

**Ammonia Vapor** The properties of saturated and superheated ammonia vapor have been determined accurately by the NBS (*Circ.* 142, 1923). The principal properties are given in Tables 33 and 34 and Fig. 24. Properties of aqua-ammonia are given in Fig. 26.

In these tables, the entropy  $s_f$  and the heat of the liquid  $h_f$  are taken as zero at -40°F instead of at 32°F, as is customary in most tables.

**Properties of Other Refrigerants** Complete and consistent

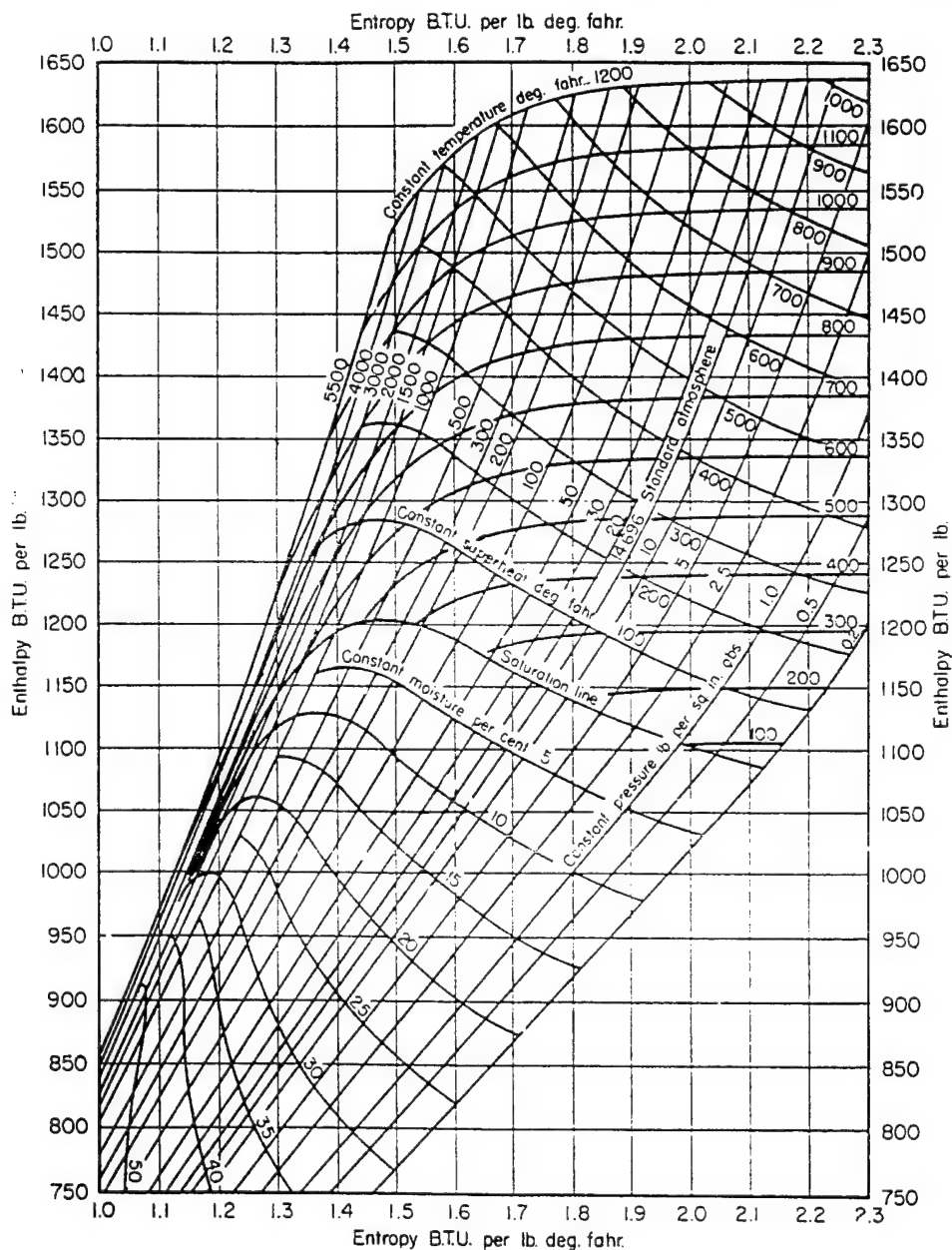


Fig. 22 Enthalpy-entropy (Mollier) chart for steam. (From "Steam, Its Generation and Use," The Babcock & Wilcox Co., 1963.)

Pipe and Block  
Insulation

## Nominal Pipe Size 18" Metal Jacket

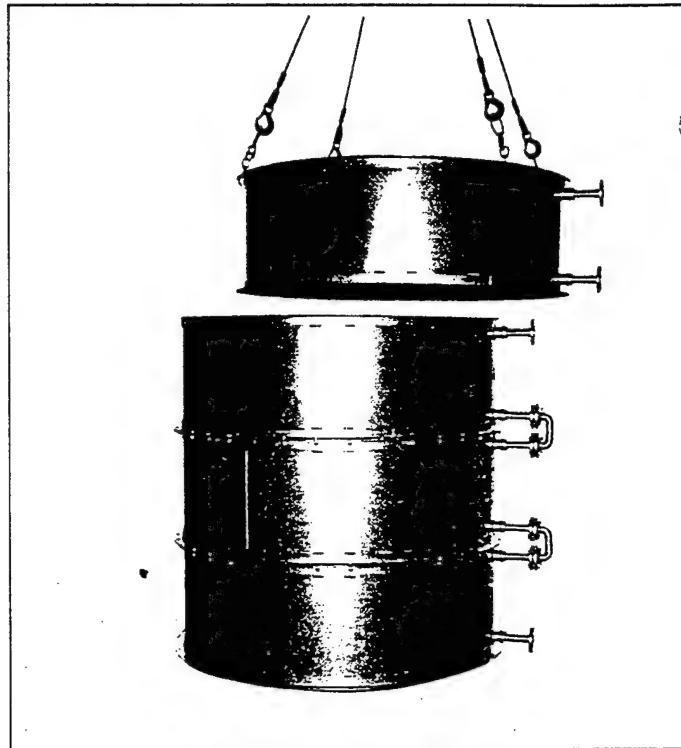
Insulation Thickness (inches)	Pipe Operating Temperature (°F)															
	200		300		400		500		600		800		1000		1200	
	HL*	ST*	HL	ST	HL	ST	HL	ST	HL	ST	HL	ST	HL	ST	HL	ST
Bare	1070	200	2442	300	4309	400	6783	500	9997	600	19265	800	33526	1000	54455	1200
1	157	122	306	153	469	183	651	213	854	245	1345	313	1978	390	2792	476
1½	123	114	236	137	360	161	497	185	650	209	1018	263	1490	325	2094	394
2	100	107	192	127	291	146	401	165	523	185	814	229	1188	280	1666	338
2½	85	103	163	120	246	136	338	152	440	169	685	207	997	250	1395	300
3	75	100	142	114	215	128	294	143	383	157	594	190	864	228	1208	271
3½	67	98	127	110	191	123	262	135	341	148	528	177	767	210	1071	249
4	59	96	113	106	170	117	232	128	302	139	467	165	677	194	945	228
4½	56	95	106	105	160	115	218	125	283	135	438	159	635	186	886	218
5	52	93	98	102	148	111	202	121	262	130	405	152	587	176	818	206
5½	48	92	91	100	137	109	187	117	242	126	375	145	542	168	756	194
6	45	91	86	99	129	106	176	114	228	122	352	140	509	161	709	186
6½	43	90	81	97	122	105	166	112	215	119	332	136	481	156	669	178
7	41	90	77	96	115	103	158	110	204	117	315	132	456	151	635	172
7½	39	89	73	95	110	101	150	108	195	114	300	129	434	146	605	166
8	37	88	70	94	105	100	144	106	186	112	287	126	415	142	578	161
8½	36	88	67	94	101	99	138	105	179	111	275	124	398	139	554	157
9	34	88	65	93	97	98	133	103	172	109	265	121	383	136	533	153
9½	33	87	63	92	94	97	128	102	166	107	256	119	369	133	514	149
10	32	87	61	92	91	96	124	101	160	106	247	117	357	130	496	146

## Nominal Pipe Size 18" Dull Surface

Insulation Thickness (inches)	Pipe Operating Temperature (°F)															
	200		300		400		500		600		800		1000		1200	
	HL*	ST*	HL	ST	HL	ST	HL	ST	HL	ST	HL	ST	HL	ST	HL	ST
Bare	1070	200	2442	300	4309	400	6783	500	9997	600	19265	800	33526	1000	54455	1200
1	193	105	366	123	554	141	760	160	991	179	1545	219	2257	264	3172	313
1½	144	98	272	112	410	126	561	140	729	154	1130	186	1644	221	2301	261
2	114	94	215	105	323	116	442	127	573	139	886	164	1285	193	1795	226
2½	95	92	179	101	269	110	367	119	476	128	735	150	1065	174	1485	202
3	82	90	155	97	232	105	317	113	410	121	632	140	915	161	1275	185
3½	73	88	137	95	205	102	280	109	362	116	558	132	807	151	1123	172
4	64	87	120	93	180	98	246	104	318	111	489	124	707	141	984	160
4½	60	87	113	92	169	97	230	102	298	108	458	121	662	136	921	154
5	55	86	104	91	156	95	212	100	274	105	422	117	609	131	847	147
5½	51	85	96	89	143	94	195	98	253	103	389	113	561	126	780	140
6	48	85	90	89	134	92	183	97	237	101	364	110	525	122	730	136
6½	45	84	85	88	127	91	172	95	223	99	343	108	495	119	688	131
7	43	84	80	87	120	91	163	94	211	98	325	106	469	116	651	128
7½	41	84	76	87	114	90	155	93	201	96	309	104	446	113	619	125
8	39	84	73	86	109	89	148	92	192	95	295	103	426	111	591	122
8½	37	83	70	86	104	89	142	91	184	94	283	101	408	109	566	119
9	36	83	67	86	100	88	137	91	177	94	271	100	392	108	544	117
9½	35	83	65	85	97	88	132	90	170	93	261	99	377	106	524	115
10	33	83	62	85	93	87	127	90	164	92	252	98	364	105	506	113

HL: Heat Transfer, BTU/hr. per linear ft.  
ST: Surface Temperature, °F.

# System



The Clayton Waste Heat Recovery System can be used to generate steam or high temperature hot water. Typical combinations of an exhaust gas or waste heat unit with a direct-fired steam generator are shown below and on the next page. Similar combinations are available for high temperature hot water production.

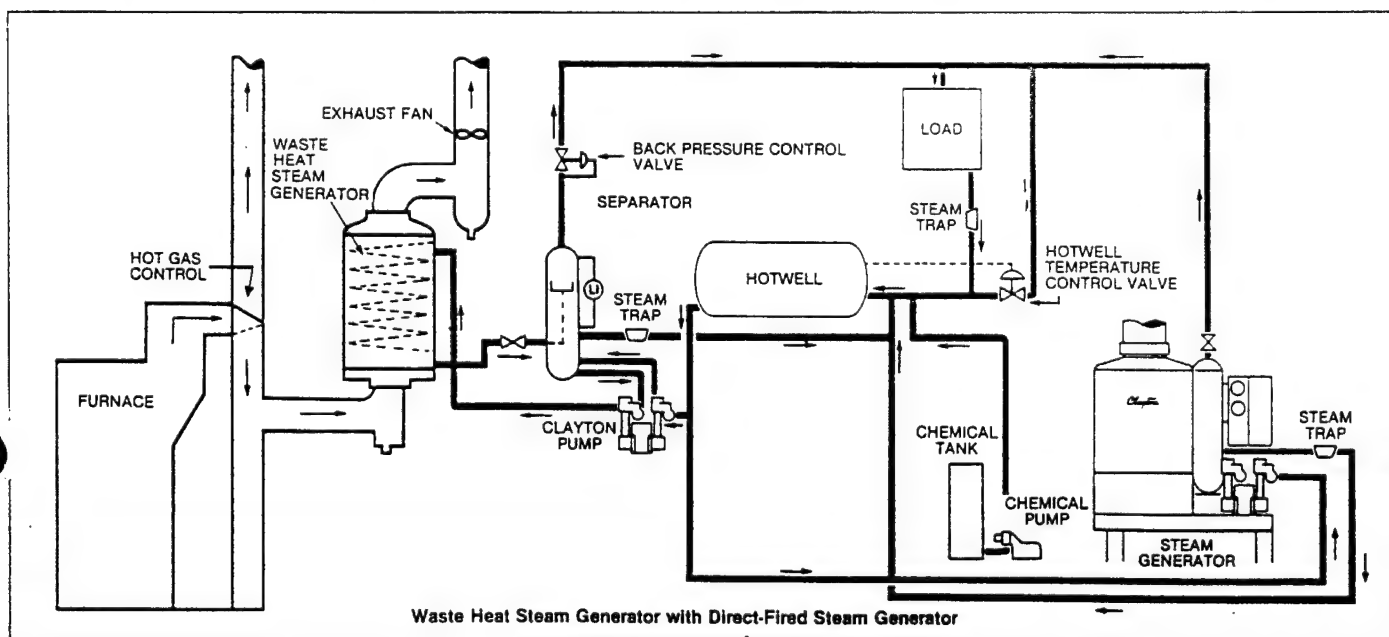
A principal feature of the Clayton Waste Heat Steam Generator is its unique coil design. The coil tube is wound in a spiral pattern with planned and closely controlled spacing between the turns. This provides the desired area to control the velocities of the combustion gases.

Various sizes of boiler tubing with relatively small internal volumes are used in the coil. This highly efficient heating surface arrangement minimizes size and weight

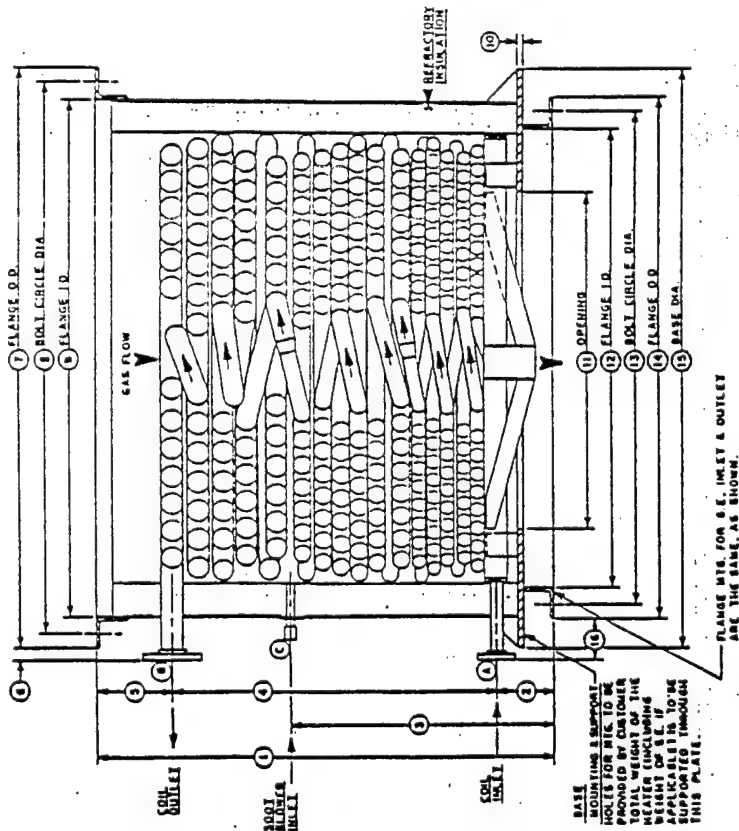
requirements. Several sizes of coils are available in standard production.

The Exhaust Gas Steam Generator has a somewhat different construction. Its heating section may differ in diameter, quantity of coils per section and flue gas area. A set of four or six coils and pipe sizes from 1" to 2" are used. Combinations are put together to produce the required steam output. This provides flexibility in matching exhaust gas rates with standard size sections.

In applications where gas temperatures are below 427° C (800° F)—typical of marine diesels—the steam or hot water flow in any section of the unit can be bypassed if one of the spiral coils is damaged. Although the steam or hot water output would be reduced after bypass, complete shutdown is not necessary.







FLANGE MTS. FOR G.E. INLET & OUTLET  
ARE THE SAME. AS SHOWN.

**NOTE:**  
CON. TUBING MAT'L. IS ASME SA 176 GRADE A.  
ALL OTHERS OF MILD STEEL.

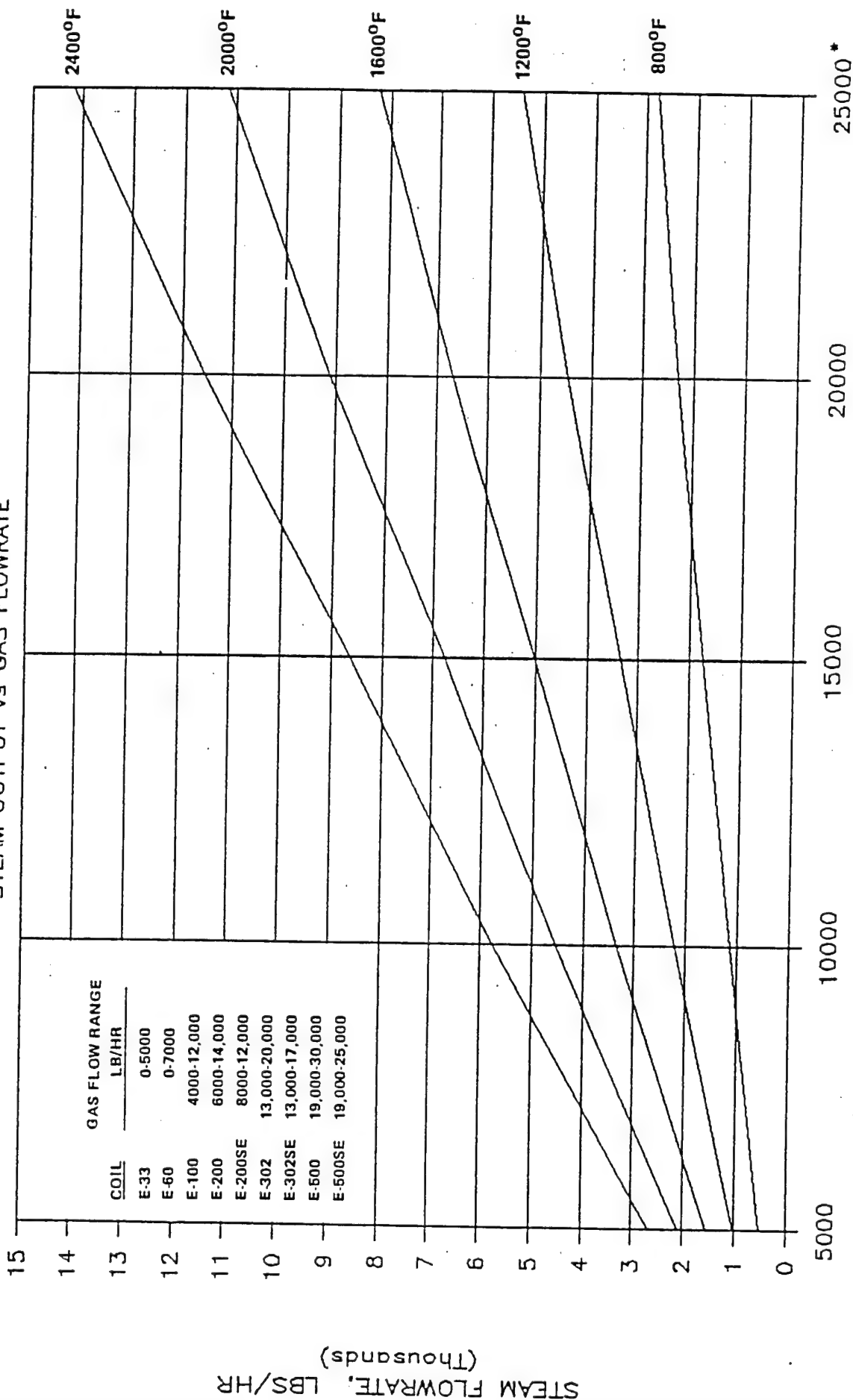
MODEL E-500WHSG

LEGEND	
(A)	1-1/4" 300 # FLANGE
(B)	2-1/2" 300 # FLANGE
(C)	1" FIFINPT.
(D)	60.00
(E)	7.75
(F)	24.84
(G)	43.06
(H)	8.19
(I)	1.94
(J)	72.75 0.0
(K)	8.12 5 CD 9/16 DIA., 24 HOLES
(L)	84.75
(M)	374" THICK
(N)	42.00
(O)	58.18 1D
(P)	83.25 CD 9/16 DIA., 24 HOLES
(Q)	68.18 0D
(R)	73.00 0.0
(S)	5.50
(T)	7839 LB
(U)	9250 LB
(V)	108.2 GAL
(W)	771.4 F12
(X)	WEIGHT DAY
(Y)	WEIGHT NIGHT
(Z)	WEIGHT WEEK NET
(1)	VOLUME
(2)	HEATING
(3)	HEATING SURFACE
ECONOMIZER SECTION	
(4)	WEIGHT
(5)	WEIGHT
(6)	WEIGHT
(7)	WEIGHT
(8)	WEIGHT
(9)	WEIGHT
(10)	WEIGHT
(11)	WEIGHT
(12)	WEIGHT
(13)	WEIGHT
(14)	WEIGHT
(15)	WEIGHT
(16)	WEIGHT
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(99)	WEIGHT
(100)	WEIGHT

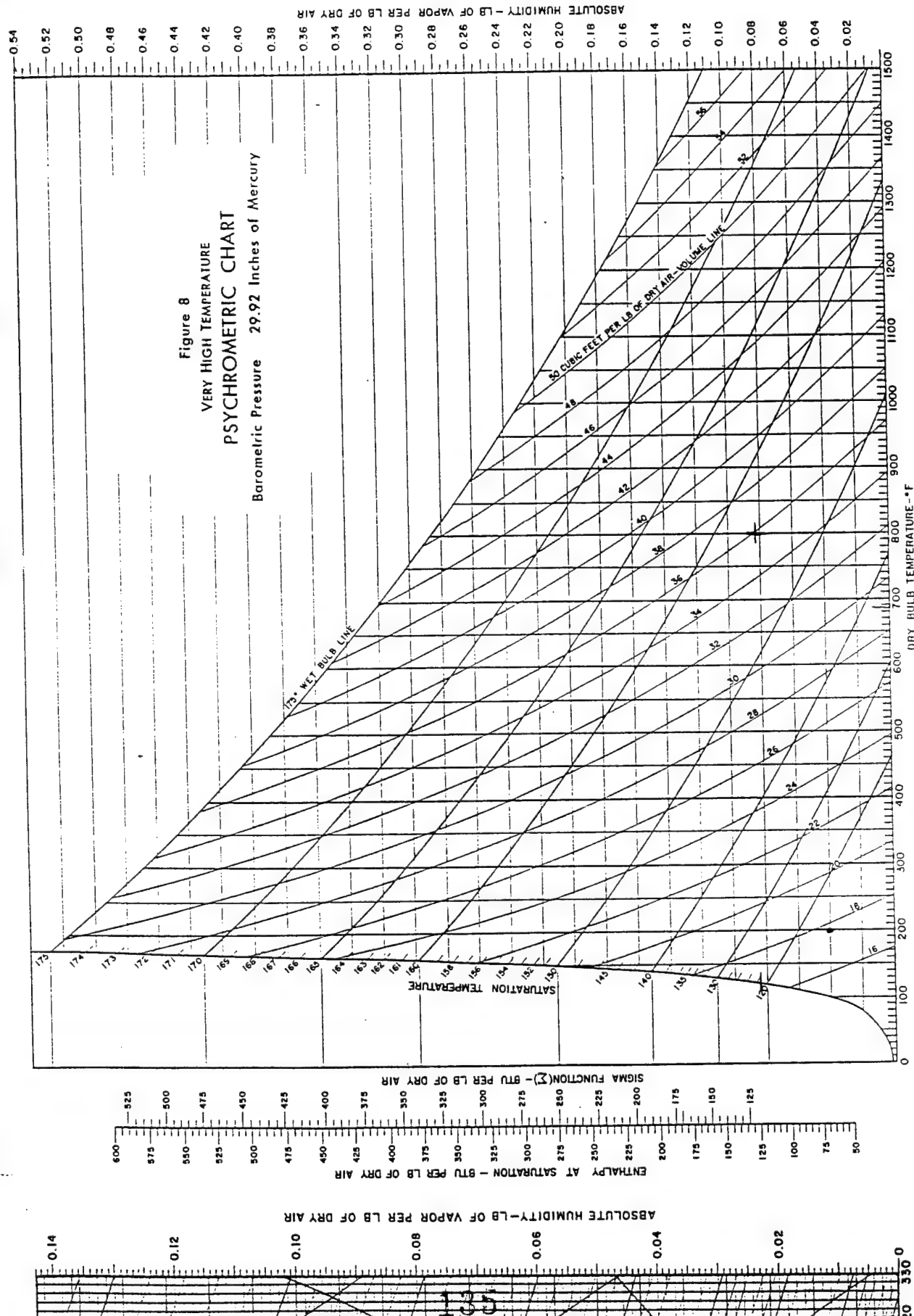
ITEM	DESCRIPTION OF PART	BILL OF MATERIAL	SIZE	QTY
CLAYTON MFG. CO. 11 MONTCLIFF, ILL.				
NAME PLAN DIMENSIONAL WASTE HEAT STEAM GENERATOR DOWNFLOW				
DATE	10-1-58	MOBILE	200 302 & 300 100	100
ITEM	100	BASE RISE QTY	1 EA	100
DATE	10-1-58	MOBILE	200 302 & 300 100	100
ITEM	100	BASE RISE QTY	1 EA	100
DATE	10-1-58	MOBILE	200 302 & 300 100	100
ITEM	100	BASE RISE QTY	1 EA	100
DATE	10-1-58	MOBILE	200 302 & 300 100	100
ITEM	100	BASE RISE QTY	1 EA	100
DATE	10-1-58	MOBILE	200 302 & 300 100	100
ITEM	100	BASE RISE QTY	1 EA	100
DATE	10-1-58	MOBILE	200 302 & 300 100	100
ITEM	100	BASE RISE QTY	1 EA	100
DATE	10-1-58	MOBILE	200 302 & 300 100	100
ITEM	100	BASE RISE QTY	1 EA	100
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ITEM	100	BASE RISE QTY	1 EA	100
DATE	10-1-58	MOBILE	200 302 & 300 100	100
ITEM	100	BASE RISE QTY	1 EA	100
DATE	10-1-58	MOBILE	200 302 & 300 100	100
ITEM	100	BASE RISE QTY	1 EA	100
DATE	10-1-58	MOBILE	200 302 & 300 100	100
ITEM	100	BASE RISE QTY	1 EA	100
DATE	10-1-58	MOBILE	200 302 & 300 100	100
ITEM	100	BASE RISE QTY	1 EA	100
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DATE	10-1-58	MOBILE	200 302 & 300 100	100
ITEM	100	BASE RISE QTY	1 EA	100
DATE	10-1-58	MOBILE	200 302 & 300 100	100
ITEM	100	BASE RISE QTY	1 EA	100
DATE	10-1-58	MOBILE	200 302 & 300 100	100
ITEM	100	BASE RISE QTY	1 EA	100
DATE	10-1-58	MOBILE	200 302 & 300 100	100
ITEM	100	BASE RISE QTY	1 EA	100
DATE	10-1-58	MOBILE	200 302 & 300 100	100
ITEM	100	BASE RISE QTY	1 EA	100
DATE	10-1-58	MOBILE	200 302 & 300 100	100
ITEM	100	BASE RISE QTY	1 EA	100
DATE	10-1-58	MOBILE	200 302 & 300 100	100
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ITEM	100	BASE RISE QTY	1 EA	100
DATE	10-1-58	MOBILE	200 302 & 300 100	100
ITEM	100	BASE RISE QTY	1 EA	100
DATE	10-1-58	MOBILE	200 302 & 300 100	100
ITEM	100	BASE RISE QTY	1 EA	100
DATE	10-1-58	MOBILE	200 302 & 30	

# CLAYTON WHSG PERFORMANCE

STEAM OUTPUT vs GAS FLOWRATE



S/HR.



may be obtained  
That is, the  
vapor pressure  
perature must  
that temperature

Barometric  
Psychrometric  
Equations 17  
constant wet  
dard baromet  
ing lines at st  
increases wit  
either relative  
temperatures  
In many c  
ignored. How  
lations may  
Hg baromet

- source sound power level, dB re 1 pW
- room volume, ft<sup>3</sup>
- octave-band center frequency, Hz
- distance from the source to the reference point, ft
- equation (1) applies directly to a single sound source

# INTERNAL COMBUSTION ENGINES - OBERT

ii

## APPENDIX

TABLE IIA  
APPROXIMATE HEAT-CAPACITY EQUATIONS\*

Gas	Molecular Weight	Specific Heat at Constant Pressure ( $c_p$ ), Btu lb <sup>-1</sup> R <sup>-1</sup> $T$ = Rankine Degrees	Range R	Maximum Deviation from Experimental Data (per cent)
N <sub>2</sub> .....	28.02	$0.227 + 0.0000292T$	720-1900	Less than 1
H <sub>2</sub> O .....	18.016	$0.433 + 0.0000166T$	720-1900	.....
CO <sub>2</sub> .....	44.00	$0.186 + 0.0000625T$	720-1900	Less than 3
CO .....	28.00	$0.226 + 0.0000321T$	720-1900	Less than 1
H <sub>2</sub> .....	2.016	$3.35 + 0.000114T$	720-1900	Less than 1
CH <sub>4</sub> .....	16.03	$0.208 + 0.000561T$	720-1900	.....
O <sub>2</sub> .....	32.00	$0.200 + 0.0000353T$	720-1900	Less than 1
Air .....	28.96	$0.220 + 0.0000306T$	720-1900	Less than 1
C <sub>3</sub> H <sub>18</sub> .....	114.14	$0.105 + 0.000486T$	720-1900	.....

\*E. S. Taylor, W. A. Leary, and J. R. Diver, *Effect of Fuel-Air Ratio, Inlet Temperature and Exhaust Pressure on Detonation*, NACA Report No. 699 (1940).

TABLE IIB  
HEAT-CAPACITY EQUATIONS\*

Gas or Vapor	Equation $c_p$ in Btu mole <sup>-1</sup> R <sup>-1</sup>	Range R	Maximum Error (per cent)
O <sub>2</sub> .....	$c_p = 11.515 - \frac{172}{\sqrt{T}} + \frac{1530}{T}$ $= 11.515 - \frac{172}{\sqrt{T}} + \frac{1530}{T} + \frac{0.05}{1000} (T - 4000)$	540-5000	1.1
N <sub>2</sub> .....	$c_p = 9.47 - \frac{3.47 \times 10^3}{T} + \frac{1.16 \times 10^6}{T^2}$	540-9000	1.7
CO .....	$c_p = 9.46 - \frac{3.29 \times 10^3}{T} + \frac{1.07 \times 10^6}{T^2}$	540-9000	1.1
H <sub>2</sub> .....	$c_p = 5.76 + \frac{0.578}{1000} T + \frac{20}{\sqrt{T}}$ $= 5.76 + \frac{0.578}{1000} T + \frac{20}{\sqrt{T}} + \frac{0.33}{1000} (T - 4000)$	540-4000 4000-9000	0.8 1.4
H <sub>2</sub> O .....	$c_p = 19.86 - \frac{597}{\sqrt{T}} + \frac{7500}{T}$	540-5400	1.8
CO <sub>2</sub> .....	$c_p = 16.2 - \frac{6.53 \times 10^3}{T} + \frac{1.41 \times 10^6}{T^2}$	540-6300	0.8
CH <sub>4</sub> .....	$c_p = 4.52 + 0.00737T$	540-1500	1.2
C <sub>2</sub> H <sub>4</sub> .....	$c_p = 4.23 + 0.01177T$	350-1100	1.5
C <sub>2</sub> H <sub>6</sub> .....	$c_p = 4.01 + 0.01636T$	400-1100	1.5
C <sub>3</sub> H <sub>18</sub> .....	$c_p = 7.92 + 0.0601T$	400-1100	Est. 4
C <sub>12</sub> H <sub>26</sub> .....	$c_p = 8.68 + 0.0889T$	400-1100	Est. 4

\*R. L. Sweigert and M. W. Beardsley, *Empirical Specific Heat Equations Based upon Spectroscopic Data*, Georgia School of Technology Bulletin, Vol. 1, No. 3 (June, 1935).

AI

TA  
Gas-Con

Gas	Chemical Formula	Molecular Weight M
Acetylene .....	C <sub>2</sub> H <sub>2</sub>	26.0
Air .....		28.9
Ammonia .....	NH <sub>3</sub>	17.0
Argon .....	A	39.9
Butane .....	C <sub>4</sub> H <sub>10</sub>	58.0
Carbon dioxide .....	CO <sub>2</sub>	44.0
Carbon monoxide .....	CO	28.0
Dodecane .....	C <sub>12</sub> H <sub>26</sub>	170.3
Ethane .....	C <sub>2</sub> H <sub>6</sub>	30.0
Ethylene .....	C <sub>2</sub> H <sub>4</sub>	28.0
Helium .....	He	4.0
Hydrogen .....	H <sub>2</sub>	2.0
Methane .....	CH <sub>4</sub>	16.0
Nitrogen .....	N <sub>2</sub>	28.0
Octane .....	C <sub>8</sub> H <sub>18</sub>	114.1
Oxygen .....	O <sub>2</sub>	32.0
Propane .....	C <sub>3</sub> H <sub>8</sub>	44.0
Sulphur dioxide .....	SO <sub>2</sub>	64.0
Water vapor .....	H <sub>2</sub> O	18.0

## 6-10 GENERAL PROPERTIES OF MATERIALS

### Specific Gravity and Density of Water at Atmospheric Pressure (Weights are in vacuo)

Temp, °C	Specific gravity	Density,		Temp, °C	Specific gravity	Density,	
		lb/ft <sup>3</sup>	kg/m <sup>3</sup>			lb/ft <sup>3</sup>	kg/m <sup>3</sup>
0	0.99987	62.4183	999.845	40	0.99224	61.9428	992.228
2	0.99997	62.4246	999.946	42	0.99147	61.894	991.447
4	1.00000	62.4266	999.955	44	0.99066	61.844	990.647
6	0.99997	62.4246	999.946	46	0.98982	61.791	989.797
8	0.99988	62.4189	999.854	48	0.98896	61.737	988.931
10	0.99973	62.4096	999.706	50	0.98807	61.682	988.050
12	0.99952	62.3969	999.502	52	0.98715	61.624	987.121
14	0.99927	62.3811	999.272	54	0.98621	61.566	986.192
16	0.99897	62.3623	998.948	56	0.98524	61.505	985.215
18	0.99862	62.3407	998.602	58	0.98425	61.443	984.222
20	0.99823	62.3164	998.213	60	0.98324	61.380	983.213
22	0.99780	62.2894	997.780	62	0.98220	61.315	982.172
24	0.99732	62.2598	997.304	64	0.98113	61.249	981.113
26	0.99681	62.2278	996.793	66	0.98005	61.181	980.025
28	0.99626	62.1934	996.242	68	0.97894	61.112	978.920
30	0.99567	62.1568	995.656	70	0.97781	61.041	977.783
32	0.99505	62.1179	995.033	72	0.97666	60.970	976.645
34	0.99440	62.0770	994.378	74	0.97548	60.896	975.460
36	0.99371	62.0341	993.691	76	0.97428	60.821	974.259
38	0.99299	61.9893	992.973	78	0.97307	60.745	973.041

### PHYSICAL DATA

#### Average Composition of Air between Sea Level and 90 km Altitude and Dry

Element	Formula	% by vol.	% by mass	Molecular weight
Nitrogen	N <sub>2</sub>	78.084	75.55	28.0134
Oxygen	O <sub>2</sub>	20.948	23.15	31.9988
Argon	Ar	0.934	1.325	39.948
Carbon dioxide	CO <sub>2</sub>	0.0314	0.0477	44.00995
Neon	Ne	0.00182	0.00127	20.183
Helium	He	0.00052	0.000072	4.0026
Krypton	Kr	0.000114	0.000409	83.80
Methane	CH <sub>4</sub>	0.0002	0.000111	16.043

From 0.0 to 0.00005 percent by volume of 9 other gases.

Average composite molecular weight of air 28.9644.

Data from "U.S. Standard Atmosphere, 1962," Government Printing Office.

#### Volume of Water as a Function of Pressure and Temperature (From "International Critical Tables")

Temp, °F (°C)	Pressure in atmospheres							
	0	500	1,000	2,000	3,000	4,000	5,000	
32(0)	1.0000	0.9769	0.9566	0.9223	0.8954	0.8739	0.8565	0.8361
68(20)	1.0016	0.9804	0.9619	0.9312	0.9065	0.8855	0.8675	0.8444
122(50)	1.0128	0.9915	0.9732	0.9428	0.9183	0.8974	0.8792	0.8562
176(80)	1.0287	1.0071	0.9884	0.9568	0.9315	0.9097	0.8913	0.8679

TABLE 136—PROPERTIES OF LIQUIDS

Liquid	Formula	Spec. Grav.	Spec. Heat	Latent Heat	Vapor Press.	Abv. Visc.	Therm. Cond.
		H <sub>2</sub> O = 1	$c_p$ Btu/lb.-°F	$\lambda$ , Btu/lb.	$e$ , in. Hg	$\mu$	$k$ (in.) 54°F
Acetic acid	C <sub>2</sub> H <sub>4</sub> O <sub>2</sub>	1.045	.468	174	.461	1.22	.099
Acetone	C <sub>3</sub> H <sub>6</sub> O	.791	.528	237	7.28	.331	.102
Ammonia	NH <sub>3</sub>	.618	1.13	518	2.53	.266	.29
Amyl acetate	C <sub>7</sub> H <sub>14</sub> O <sub>2</sub>	.871	.459	187	.002	.806	.073
Aniline	C <sub>6</sub> H <sub>5</sub> NH <sub>2</sub>	1.022	.495	188	3.01	4.47	.099
Benzene	C <sub>6</sub> H <sub>6</sub>	.879	.406	188	.002	.647	.081
Brine—25%	NaCl	1.228	.687	814	61.5	2.02	.318
Brine—25%	NaCl	1.189	.814	158	17.4	2.02	.265
Bulane	C <sub>4</sub> H <sub>10</sub>	.579	.550	158	.002	.187	.076
Carbon dioxide	CO <sub>2</sub>	1.101	.92	63.1	1690	.071	.083
Carbon disulfide	CS <sub>2</sub>	1.263	.240	157	11.60	.376	.083
Carbon tetrachloride	CCl <sub>4</sub>	1.594	.201	93.8	3.58	.958	.061
Chloroform	CHCl <sub>3</sub>	1.489	.234	113	6.27	.563	.070
Ethyl acetate	C <sub>4</sub> H <sub>8</sub> O <sub>2</sub>	.901	.459	183	2.87	.455	.084
Ethyl alcohol	C <sub>2</sub> H <sub>5</sub> O	.789	.622	368	1.73	1.19	.101
Ethyl alcohol—40%	C <sub>2</sub> H <sub>5</sub> O	.935	.920	151	17.4	1.25	.224
Ethyl ether	C <sub>2</sub> H <sub>5</sub> O	.708	.503	344	.002	.245	.073
Ethylene glycol	C <sub>2</sub> H <sub>4</sub> O <sub>2</sub>	1.115	.57	344	.002	20.9	.167
Ethylene glycol—50%	C <sub>2</sub> H <sub>4</sub> O <sub>2</sub>	1.067	.70	178	.40	4.1	.242
Freon 11—12.87 psia	CFCl <sub>3</sub>	1.490	.214	78.9	27.3	.46	.064
Freon 12—82.28 psia	CF <sub>2</sub> Cl <sub>2</sub>	1.331	.253	60.6	153	.27	.052
Freon 22—133 psia	CHF <sub>2</sub> Cl	1.215	.298	81.0	27.9	.24	.062
Gasoline	C <sub>8</sub> H <sub>18</sub>	.687	.70	157	3.5	3.5	.162
Glycerol	C <sub>3</sub> H <sub>8</sub> O <sub>3</sub>	1.261	.573	157	1.30	4.16	.082
Heptane	C <sub>7</sub> H <sub>16</sub>	.684	.508	157	4.56	.326	.088
Hexane	C <sub>6</sub> H <sub>14</sub>	.659	.537	157	1.30	4.16	.082
Hydrochloric acid—40%	HCl	1.198	.60	178	1.30	4.16	.082
Kerosene	C <sub>15</sub> H <sub>32</sub>	.82	.50	178	1.30	4.16	.082
Methyl acetate	C <sub>4</sub> H <sub>8</sub> O <sub>2</sub>	.933	.468	190	6.68	1.8	.085
Methyl alcohol	CH <sub>3</sub> O	.792	.610	499	3.78	.388	.093
Methyl chloride	CH <sub>3</sub> Cl	.92	.385	172	1.44	.593	.120
Milk		1.03	.93	172	1.44	.183	.089
Nitric acid	HNO <sub>3</sub>	1.502	.523	206	.417	1.77	.091
Oil, draft gage	C <sub>12</sub> H <sub>22</sub>	.834	.53	156	.417	3.42	.091
Oil, linseed	C <sub>18</sub> H <sub>34</sub>	.941	.45	33	33	200	.080
Oil, lube. (med.)	C <sub>18</sub> H <sub>34</sub>	.91	.33	84	84	200	.109
Oil, olive	C <sub>18</sub> H <sub>34</sub>	.92	.33	84	84	200	.109
Oil, vegetable	C <sub>18</sub> H <sub>34</sub>	.92	.33	84	84	200	.109
Phenol	C <sub>6</sub> H <sub>5</sub> O	.626	.527	158	.001	40.6	.069
Propene	C <sub>3</sub> H <sub>6</sub>	1.071	.561	158	.001	12.7	.075
Sulfur dioxide—98%	SO <sub>2</sub>	1.434	.35	150	258	14	.115
Toluene	C <sub>7</sub> H <sub>8</sub>	.866	.407	178	96.5	.27	.105
Turpentine	C <sub>10</sub> H <sub>16</sub>	.867	.472	133	.870	.390	.074
Water, 39.2°F (4°C)	H <sub>2</sub> O	1.000	1.005	1069	.240	1.567	.325
Water, 59°F (15°C)	H <sub>2</sub> O	.999	1.000	1058	.504	1.140	.339
Water, 68.7°F	H <sub>2</sub> O	.998	.998	1054	.707	1.000	.346
Water, 70°F (21°C)	H <sub>2</sub> O	.998	.998	1053	.739	.978	.347
Water, 212°F (100°C)	H <sub>2</sub> O	.958	1.006	970	29.92	.284	.393
Water, heavy	D <sub>2</sub> O	1.108	1.018	894	29.92	1.03	.349
Water, sea		1.025	.94				

Adapted from the data of N. A. Lange, "Handbook of Chemistry," Handbook Publishers, Inc., Sandusky, Ohio, 1952. Refer to manufacturers' data for exact properties.

TABLE 137—PROPERTIES OF SOLIDS

Solid	Density $\lambda$ lb./ft. <sup>3</sup>	Specific Heat $c_p$ Btu/lb.-°F	Thermal Conductivity $k$ Btu-in./hr.-ft. <sup>2</sup> -°F
Asbestos.....	153	.20	1.7
Asbestos—cement board.....	120	—	4.0
Ashes.....	43	.20	0.5
Asphalt.....	82	—	5.2
Bakelite.....	86	.33	—
Borax.....	109	.38	—
Brick, common.....	120	.22	5.0
Brick, face.....	130	.22	9.0
Calcium carbonate.....	177	.19	14.4
Calcium chloride.....	134	.16	—
Carborundum.....	195	.16	1.5
Celluloid.....	87	.36	1.4
Cellulose.....	94	.37	—
Cement, loose.....	94	.20	2.1
Cement, mortar.....	116	.20	5.0
Chalk.....	142	.21	5.8
Charcoal, hardwood.....	34	.20	—
Cinders, loose.....	43	.18	—
Clay, dry.....	63	.22	—
Clay, moist.....	110	.55	—
Coal, anth., solid.....	98	.31	—
Coal, bitum., solid.....	85	.30	—
Coke, solid.....	75	.20	—
Concrete, cinder.....	97	.18	3.5
Concrete, stone.....	140	.19	12.5
Cork.....	15	.48	0.4
Corkboard.....	8	—	0.3
Cotton.....	5	.32	0.4
Dry ice.....	97	.12	—
Earth, moist.....	78	.44	12.0
Ebonite.....	72	.35	1.2
Felt.....	58	.46	—
Feldspar.....	160	.20	16.2
Flannel.....	—	—	0.7
Glass, crown.....	160	.16	5.5
Glass, flint.....	215	.13	4.1
Glass, pyrex.....	140	.20	7.5
Granite.....	165	.19	12.5
Graphite.....	99	.20	306
Gypsum, compressed.....	152	.26	9.0
Gypsum board.....	50	—	1.4
Hay, baled.....	20	.32	—

TABLE 6.3 Enthalpies and Gibbs Energies of Formation, Entropies, and Heat Capacities of the Elements and Inorganic Compounds (Continued)

LANGE'S HANDBOOK  
OF CHEMISTRY

14<sup>th</sup> EDITION

MCGRAW-HILL

Substance	State	$\Delta H_f^\circ$ , kJ·mol <sup>-1</sup>	$\Delta G_f^\circ$ , kJ·mol <sup>-1</sup>	$S^\circ$ , J·deg <sup>-1</sup> ·mol <sup>-1</sup>	$C_p$ , J·deg <sup>-1</sup> ·mol <sup>-1</sup>
Nb <sub>2</sub> O <sub>5</sub>	c	-1 899.5(42)	-1 765.8	137.3(13)	112
NbOCl <sub>3</sub>	c	-879.5	-782	159	138
Nitrogen					
N <sub>2</sub>	g	0	0	191.61(2)	33
NF <sub>3</sub>	g	-132.1(11)	-90.6	260.8(2)	59
N <sub>2</sub> F <sub>2</sub> <i>cis</i>	g	67	109	259.8	58
<i>trans</i>	g	81.2	120.5	262.6	58
N <sub>2</sub> H <sub>4</sub> hydrazine	lq	50.6(11)	150.1	121.5(4)	98
N <sub>2</sub> H <sub>4</sub> hydrazine- <i>d</i> <sub>4</sub>	g	81.6	150.9	248.86	55
N <sub>2</sub> H <sub>4</sub> <sup>+</sup> std. state	aq	-7.5	82.4	151	73
N <sub>2</sub> H <sub>3</sub> Br	c	-155.6			
std. state	aq	-128.9	-21.8	233.1	-71
N <sub>2</sub> H <sub>3</sub> Cl	c	-197.1			
std. state	aq	-174.9	-49.0	207.1	-61
N <sub>2</sub> H <sub>3</sub> Cl·HCl	c	-367.4			
N <sub>2</sub> H <sub>3</sub> OH	lq	-242.7			
undissoc; ss	aq	-251.50	-109.2	207.9	72
N <sub>2</sub> H <sub>3</sub> NO <sub>3</sub>	c	-251.58			
std. state	aq	-215.10	-28.91	297	
(N <sub>2</sub> H <sub>3</sub> ) <sub>2</sub> SO <sub>4</sub>	c	-959.0			
std. state	aq	-924.7	-579.9	322	-151
NO	g	90.29(17)	86.60	210.76	38
NOBr	g	82.13	82.42	273.42	45
NOCl	g	51.71(42)	66.10	261.68(17)	49
NOF	g	-65.7(17)	-50.3	248.02	41
NOF <sub>3</sub>	g	-163	-96	278.40	57
NO <sub>2</sub>	g	33.1(8)	51.3	240.03(13)	35
NO <sub>2</sub> Cl	g	12.1(17)	54	272.19	51
NO <sub>2</sub> F	g	-109.(21)	-66	250.2	45
NO <sub>3</sub>	g	69.41	114.35	252.5	49
N <sub>2</sub> O	g	82.4(4)	104.2	220.0	36
N <sub>2</sub> O <sub>2</sub>	g	170.37	202.88	287.52	63
N <sub>2</sub> O <sub>2</sub> <sup>-</sup> hyponitrite	aq	-17.2	138.9	27.6	55
N <sub>2</sub> O <sub>3</sub>	g	82.8(8)	139.7	308.5(21)	69
N <sub>2</sub> O <sub>4</sub>	lq	-19.56	97.52	209.20	72
	g	9.08	97.79	304.38	65
N <sub>2</sub> O <sub>5</sub>	g	11.3(18)	118.0	346.5(42)	81
Osmium					
Os	c	0	0	32.6	47
OsCl <sub>3</sub>	c	-190.4	-121	130	
OsCl <sub>4</sub>	c	-254.8	-159	155	
OsO <sub>4</sub>	c	-394.1	-305.0	143.9	
Oxygen					
O <sub>2</sub>	g	0	0	205.147(35)	33
O <sub>3</sub>	g	142.7(17)	163.2	238.9	59
OF <sub>2</sub>	g	24.5(16)	41.8	247.5(4)	58
O <sub>2</sub> F <sub>2</sub>	g	19.79	61.42	268.11	64
Palladium					
Pd	c	0	0	37.91	47



## Combustion Constants

\*Carbon and sulfur are considered as gases for molal calculations only.

Note: This table is reprinted from *Fuel Flue Cases*, 1941 Edition, courtesy of American Gas Association.

All gas volumes corrected to 60 F and 30 in. Hg dry.



Fig. 94-1

# PHYSICAL PROPERTIES — Liquids and Misc.

	mol. wt	sp gr 60-70F	sp ht 60F	mp F	bp F	LH	k	Viscosity centipoises				Viscosity SSU			
								40C	26.7C	40C	71C	40C	26.7C	40C	71C
								40F	80F	120F	160F	40F	80F	120F	160F
<b>Acids</b>															
Acetic acid, 100%	60	1.05	.48	62	245	175 <sup>1</sup>	.095	1.65	1.18	0.85	0.65				
Acetic acid, 10%		1.01	.96												
Fatty acid — oleic	282	0.89		13	547		.092								
Fatty acid — palmitic	256	0.853	.653	146	520	21.8	.083								
Fatty acid — stearic	284	0.847	.550	157	721	26.4	.078								
Hydrochloric acid 31.5% (muriatic)		1.15	.6	-53				2.5	1.85	1.42	1.1				
Hydrochloric acid 10% (muriatic)		1.05	.75					1.45	1.05	.8	.61				
Nitric acid, 95%		1.50	.5	-44	187			7.4	2.2	1.5	1.05				
Nitric acid, 60%		1.37	.64	-9.4											
Nitric acid, 10%		1.05	.9												
Phenol (carbolic acid)	94	1.07	.56	106	346	16.1		14.5	7.3	3.9	2.1				
Phosphoric acid, 20%		1.11	.85												
Phosphoric acid, 10%		1.05	.93												
Sulfuric acid, 110% (fuming)			.27	92	342			82.0	41.0	22.0	12.2	280	100	55	37
Sulfuric acid, 98%		1.84	.35	28.6	625	219 <sup>1</sup>	.15	46.0	23.0	11.5	6.4	118	68	45	
Sulfuric acid, 60%		1.50	.52	-20	282		.24	8.9	5.8	3.9	2.7				
Sulfuric acid, 20%		1.14	.84	8	218			2.5	1.4	0.8	0.55				
<b>Water solutions</b>															
Brine — calcium chloride, 25%		1.23	.689	-21			.28	4.5	2.1	0.95	0.52				
Brine — sodium chloride, 25%		1.19	.786	-16	221		.24	3.3	2.1	1.3	.92				
Sea water		1.03	.94												
Sodium hydroxide, 50% (caustic soda)		1.53	.78					250.0	77.0	26.0	9.5	950	240	84	46
Sodium hydroxide, 30%		1.33	.84					9.6	4.5	2.5	1.5				
Water	18	1.0	1.0	32	212	144	.34	1.55	0.86	0.56	0.4				
<b>Food Products*</b>															
Dextrose, corn syrup 40° Baume		1.38			225							170000	11000	1700	430
Dextrose, corn syrup 45° Baume		1.45			237							2x10 <sup>5</sup>	120000	12000	
Fish, fresh, avg.			.76			101									
Fruit, fresh, avg.			.88			120									
Honey			.34			30									
Ice		.9	.5			144									
Ice cream			.70			96									
Lard		.92	.64			22						10000	450	155	88
Maple syrup			.48			52									
Meat, fresh, avg.			.70			90									
Milk, 3.5%		1.03	.90			124									
Molasses, primary A			.6												
Molasses, secondary B												10000	2600		
Molasses, blackstrap (final) C												70000	10000		
Starch		1.53										300000	25000		
Sucrose, 60% sugar syrup		1.29	.74	10	218			156	41.0	14.0	7.0	500	150	68	
Sucrose, 40% sugar syrup		1.18	.66	25	214			120	5.0	2.5	1.6				
Sugar, cane & beet		1.66	.3			72									
Vegetables, fresh, avg.			.92			130									
Wines, table and dessert, avg.		1.03	.90	7 to 22											
<b>Petroleum Products</b>															
Asphalt, RS-1, MS-1, SS-1, emulsion		1.0	.42						86	34	17		400	160	85
Asphalt, RC-0, MC-0, SC-0, cut back													950	340	150
Asphalt, RC-3, MC-3, SC-3, cut back													40000	7000	1600
Asphalt, RC-5, MC-5, SC-5, cut back													500000	45000	8000
Asphalt, 100-120 penetration		1.0											3500 at 250F		
Asphalt, 40-50 penetration		1.01											8000 at 250F		
Benzene	78	.844	.41	42	176	170 <sup>1</sup>	.0087	8	62	46	0.30				
Gasoline		.6	.53			140 <sup>1</sup>	.0078	7	55	44	0.25				
No. 1 Fuel Oil (Kerosene)		.811	.47			110 <sup>1</sup>	.0084	33	21	14	0.95	40	36		
No. 2 Fuel Oil, — PS100		.865	.44				.008	45	26	16	1.15	43	36	33	32
No. 3 Fuel Oil, — PS200		.887	.43				.0075	150	70	40	2.9	84	52	41	37
No. 4 Fuel Oil		.901	.42				.0075	240	96	50	5.0	480	125	62	42
No. 5 Fuel Oil, — PS300		.937	.41				.0072	390.0	75.0	25.0		1600	370	125	
No. 6 Fuel Oil, — PS400		.956	.40				.0070	1000.0	155.0	40.0		4500	680	180	
Transformer oil, light		.898	.42				.0075	34.2	12.1	6.3	3.9	170	72	49	40
Transformer oil, medium		.91	.42					89.0	28.2	11.9	6.7	460	145	70	50
34° API Mid-continent crude		.855	.44				.008	15	6.5	3.0	2.0	88	51	37	34
28° API gas oil		.887	.42				.0078	25	9.0	6.0	4.0	135	59	48	41
Quench and tempering oil		.91													
SAE — 5W (=8 machine lube oil)		.88						110	30	12	7	550	160	74	51
SAE — 10W (=10 machine lube oil)								170	50	22	11	1500	265	120	64
SAE — 20 (=20 machine lube oil)		.89						580	98	33	14	2900	500	170	80
SAE — 30 (=30 machine lube oil)		.89						1200	200	60	25	5000	870	260	110
SAE — 40												8500	1400	380	150
SAE — 50												23000	3600	770	225
Paraffin, melted	92	.9	.69	100-133	660-870	70	.014								
Toluene		.862	.42	-139	23	157 <sup>1</sup>	.0084	75	.57	45	.36				
<b>Miscellaneous</b>															
Acetone, 100%	58	.789	.514	-137	133	225 <sup>1</sup>	.096	0.4	0.32	0.26	0.21				
Alcohol, ethyl, 95%		.81	.6			370	.11	2.0	1.3	.8	0.53				
Alcohol, methyl, 90%		.82	.65				.13	1.0	0.73	.53	0.43				
Ammonia, 100%	17	.77	1.1	-106	-27	589 <sup>1</sup>	.29	0.14	0.1	0.08	0.06				
Ammonia, 26%		.905	1.0				.26	1.8	1.2						
Aroclor		1.44	.28		650		.0057	2000	200	32	10	20000	500	95	48
Cotton seed oil		.95	.47				.1								
Creosote															
Dawtherm A	(See coal tars)	166	.995	.63	54	500	.08								
Dawtherm C	231	1.10	.35-.65	70-220	600	123	.08								
Ethylene glycol	62	1.11	.58	9.5	387	346 <sup>1</sup>	.153	44.0	19.0	9.0	4.5	185	86	53	39
Glue, 2 parts water, 1 part dry glue		1.09	.89												
Glycerol, 100% (glycerin)	92	1.26	.58	62.5	554	340 <sup>1</sup>	.164	490.0	130.0	56.0		25000	3100	700	230
Glycerol, 50%		1.13		-6.5			.24	11.0	5.4	2.8	1.5				
Linseed oil		.93	.44	-5.0	552			72	37	20	11				
Phthalic anhydride	148	1.53	.232	267	544	66									
Soybean oil		.92	.24-.33	3-14											
Sulfur, melted	32	1.8		239	832										
Trichloroethylene	166	1.62	.215	-99	189	90	.070	.7	0.58	0.46	0.4				
Antine, spirits of	136	.86	.42	14	320	184 <sup>1</sup>	.074	1.9	1.35	0.95	0.7				
Carbon tetrachloride	154	1.58	.21	-95	170	84 <sup>1</sup>	.095	1.3	0.95	0.72	0.56				

\* This figure is latent heat of vaporization.

\* sp ht of food products are for above freezing.

Below freezing the values are approx. 60% of those given.

mol wt — molecular weight

sp ht — Btu/lb F

mp — Melting point, F

bp — Boiling point, F

LH — Latent heat of fusion, Btu/lb

k — Thermal conductivity, Btu/sq ft hr F/ft

Table 3-37. HEAT OF DILUTION OF ACIDS\*

VIVIAN B. PARKER

$\Delta H_{dil}$ , the integral heat of dilution, is the change in enthalpy, per mole of solute, when a solution of concentration  $m_1$  is diluted to a final finite concentration  $m_2$ . When the dilution is carried out by addition of an infinite amount of solvent, so the final solution is infinitely dilute, the enthalpy change is the integral heat of dilution to infinite dilution. Since  $\Phi_L$ , the relative apparent molal enthalpy, is equal to and opposite in sign to this, only  $\Phi_L$  is referred to here.

 $\Phi_L$ , cal/mol, at 25 deg C (298.15 K)\*

$n$	$m$	HF	HCl	HClO <sub>4</sub>	HBr	HI	HNO <sub>3</sub>	CH <sub>3</sub> CO <sub>2</sub> H	C <sub>2</sub> H <sub>3</sub> O <sub>2</sub> H
$\infty$	0.00	0	0	0	0	0	0	0	0
500,000	.000111	300	5	5	5	5	5	9	40
100,000	.000555	900	10	10	9	9	11	13	50
50,000	.00111	1,300	16	14	13	12	15	20	53
20,000	.00278	1,800	25	22	22	20	23	23	55
10,000	.00555	2,130	34	30	31	29	31	25	58
7,000	.00793	2,250	40	35	37	34	36	26	59
5,000	.01110	2,360	47	40	44	41	42	26	61
4,000	.01388	2,450	54	43	49	46	46	27	62
3,000	.01850	2,550	60	47	56	52	51	28	62
2,000	.02775	2,700	74	54	68	63	59	28	63
1,500	.03700	2,812	85	58	77	71	65	29	64
1,110	.05000	2,927	97	62	89	81	73	29	65
1,000	.05551	2,969	102	62	92	84	76	29	65
900	.0617	2,989	107	63	97	88	78	30	66
800	.0694	3,015	113	64	102	92	81	31	67
700	.0793	3,037	120	65	108	96	84	32	68
600	.0925	3,057	129	65	115	102	88	32	68
555.1	.1000	3,060	133	65	119	105	89	32	69
500	.1110	3,077	140	65	124	108	92	32	70
400	.1388	3,097	156	64	135	116	97	33	72
300	.1850	3,126	176	61	150	125	103	34	76
277.5	.2000	3,129	182	59	155	128	105	35	79
200	.2775	3,142	212	50	176	140	117	36	82
150	.3700	3,148	242	36	197	154	118	39	88
111.0	.5000	3,156	280	18	225	170	119	42	97
100	.5551	3,160	295	+12	235	176	120	44	101
75	.7401	3,167	343	-14	270	194	121	49	113
55.51	1.0000	3,179	405	-48	314	223	121	54	130
50	1.1101	3,184	431	-61	331	234	121	56	147
40	1.3877	3,192	493	-91	379	260	121	60	155
37.00	1.5000	3,194	518	-103	398	269	121	62	162
30	1.8502	3,200	595	-138	455	301	124	65	183
27.75	2.0000	3,203	627	-149	477	315	126	66	192
25	2.2202	3,208	674	-162	510	336	130	67	204
22.20	2.5000	3,211	732	-173	550	365	139	68	218
20	2.7753	3,214	792	-182	590	396	149	69	233
18.50	3.0000	3,216	838	-187	624	427	159	69	245
15.86	3.500	3,221	946	-196	709	503	189	69	268
15	3.7004	3,227	988	-195	743	536	203	69	277
13.88	4.0000	3,234	1,052	-188	796	588	229	69	291
12.33	4.5000	3,246	1,171	-175	887	676	265	69	313
12	4.6255	3,249	1,190	-170	911	700	277	69	318
11.10	5.0000	3,256	1,271	-150	983	764	313	69	333
10	5.5506	3,265	1,396	-117	1,097	855	368	68	353
9.5	5.8427	3,269	1,462	-97	1,156	920	400	68	363
9.251	6.0000	3,272	1,498	-84	1,196	950	418	67	368
9.0	6.1674	3,274	1,535	-72	1,230	980	437	67	373
8.5	6.5301	3,278	1,618	-40	1,313	1,050	480	66	383
8.0	6.9383	3,282	1,710	+4	1,401	1,115	530	65	392
7.929	7.0000	3,283	1,725	11	1,416	1,130	538	65	394

\*One calorie (thermochemical) equals 4.184 joules.

\*From: NSR  
1965.

Substan:

HF  
HCl  
HClO<sub>4</sub>  
HClO<sub>4</sub>·H<sub>2</sub>O  
HBr  
HI  
HIO<sub>3</sub>  
HNO<sub>3</sub>  
HCOOH  
CH<sub>3</sub>COOH

NH<sub>3</sub>  
NH<sub>4</sub>Cl  
NH<sub>4</sub>ClO<sub>4</sub>  
NH<sub>4</sub>Br  
NH<sub>4</sub>I  
NH<sub>4</sub>IO<sub>3</sub>  
NH<sub>4</sub>NO<sub>3</sub>  
NH<sub>4</sub>NO<sub>2</sub>  
NH<sub>4</sub>C<sub>2</sub>H<sub>3</sub>O<sub>2</sub>  
NH<sub>4</sub>CN  
NH<sub>4</sub>CNS  
CH<sub>3</sub>NH<sub>2</sub>Cl  
(CH<sub>3</sub>)<sub>2</sub>NHCl  
N(CH<sub>3</sub>)<sub>2</sub>Cl  
N(CH<sub>3</sub>)<sub>2</sub>Br  
N(CH<sub>3</sub>)<sub>2</sub>I

AgClO<sub>4</sub>  
AgNO<sub>3</sub>  
AgNO<sub>2</sub>

LiOH  
LiOH·H<sub>2</sub>O  
LiF  
LiCl  
LiCl·H<sub>2</sub>O  
LiClO<sub>4</sub>  
LiClO<sub>4</sub>·3H<sub>2</sub>O  
LiBr  
LiBr·H<sub>2</sub>O

\*25 deg C =

\*From: NSR  
1965.

Table 3-37. HEAT OF DILUTION OF ACIDS (Continued)

<i>n</i>	<i>m</i>	HF	HCl	HClO <sub>4</sub>	HBr	HI	HNO <sub>3</sub>	CH <sub>3</sub> CO <sub>2</sub> H	C <sub>2</sub> H <sub>3</sub> O <sub>2</sub> H
7.5	7.4008	3,286	1,820	61	1,497	1,210	595	63	402
7.0	7.9295	3,290	1,942	135	1,608	1,325	661	61	411
6.938	8.0000	3,291	1,960	146	1,622	1,340	667	61	412
6.5	8.5394	3,296	2,090	229	1,738	1,450	745	58	420
6.167	9.0000	3,302	2,202	306	1,845	1,570	805	55	426
6.0	9.2510	3,305	2,265	348	1,903	1,630	840	53	429
5.551	10.0000	3,316	2,447	481	2,078	1,820	940	49	436
5.5	10.0920	3,317	2,472	499	2,102	1,850	950	49	437
5.0	11.1012	3,335	2,721	730	2,344	2,100	1,098	43	445
4.5	12.3346	3,362	3,025	1,144	2,655	2,460	1,270	37	453
4.0	13.8765	3,400	3,404	1,574	3,089	2,960	1,495	29	462
3.700	15.0000	3,428	3,680	1,893	3,415	3,350	1,645	26	469
3.5	15.8589	3,450	3,882	2,150	3,668	3,660	1,770	21	473
3.25	17.0788	3,483	4,160	2,460	4,005	4,110	1,920	17	481
3.0	18.5020	3,520	4,460	2,880	4,370	4,630	2,101	13	488
2.775	20.0000	3,557	4,750	3,300	4,760	5,190	2,270	9	496
2.5	22.2024	3,607	5,180	4,000	5,300	6,000	2,520	+4	506
2.0	27.7530	3,712	6,260	5,500	6,650	.....	3,060	-5	528
1.5	37.0040	.....	8,240	.....	8,530	.....	3,770	-13	532
1.0	55.506	.....	10,900	.....	11,670	.....	4,715	+11	518
0.5	111.012	.....	.....	.....	.....	.....	.....	77	495
0.25	222.02	.....	.....	.....	.....	.....	.....	129	.....

\*From: NSRDS—NBS 2, "Thermal Properties of Aqueous Uni-univalent Electrolytes", V.B. Parker, National Bureau of Standards, 1965.

Table 3-38. HEATS OF SOLUTION\*

VIVIAN B. PARKER

 $\Delta H_f$ , 25 deg C for Uni-univalent Electrolytes in H<sub>2</sub>O\*

Substance	State	$\Delta H_f$	Substance	State	$\Delta H_f$	Substance	State	$\Delta H_f$
		cal/mole			cal/mole			cal/mole
HF	g	-14,700	LiBr·2H <sub>2</sub> O	c	-2,250	KCl	c	4,115
HCl	g	-17,888	LiBrO <sub>3</sub>	c	340	KClO <sub>3</sub>	c	9,890
HClO <sub>4</sub>	l	-21,215	LiF	c	-15,130	KClO <sub>4</sub>	c	12,200
HClO <sub>4</sub> ·H <sub>2</sub> O	c	-7,875	LiF·H <sub>2</sub> O	c	-7,090	KBr	c	4,750
HBr	g	-20,350	LiF·2H <sub>2</sub> O	c	-3,530	KBrO <sub>3</sub>	c	9,830
HI	g	-19,520	LiF·3H <sub>2</sub> O	c	140	KI	c	4,860
HIO <sub>3</sub>	l	2,100	LiNO <sub>3</sub>	c	-2,630	KIO <sub>3</sub>	c	6,630
HNO <sub>3</sub>	l	-7,954	LiNO <sub>3</sub> ·H <sub>2</sub> O	c	1,880	KNO <sub>3</sub>	c	3,190
HCOOH	l	-205	LiNO <sub>3</sub>	c	-600	KNO <sub>3</sub>	c	8,340
CH <sub>3</sub> COOH	l	-360	NaOH	c	-10,637	K <sub>2</sub> C <sub>2</sub> O <sub>4</sub>	c	-3,665
NH <sub>3</sub>	g	-7,290	NaOH·H <sub>2</sub> O	c	-5,118	KCN	c	2,800
NH <sub>4</sub> Cl	c	3,533	NaF	c	218	K <sub>2</sub> CO <sub>3</sub>	c	4,840
NH <sub>4</sub> ClO <sub>4</sub>	c	8,000	NaCl	c	928	K <sub>2</sub> CNS	c	5,790
NH <sub>4</sub> Br	c	4,010	NaClO <sub>2</sub>	c	80	KMnO <sub>4</sub>	c	10,410
NH <sub>4</sub> I	c	3,280	NaClO <sub>3</sub> ·3H <sub>2</sub> O	c	6,830	RbOH	c	-14,900
NH <sub>4</sub> IO <sub>3</sub>	c	7,600	NaClO <sub>3</sub>	c	5,191	RbOH·H <sub>2</sub> O	c	-4,310
NH <sub>4</sub> NO <sub>3</sub>	c	4,600	NaClO <sub>3</sub>	c	3,317	RbOH·2H <sub>2</sub> O	c	210
NH <sub>4</sub> NO <sub>3</sub>	c	6,140	NaClO <sub>3</sub> ·H <sub>2</sub> O	c	5,380	RbF	c	-6,240
NH <sub>4</sub> C <sub>2</sub> H <sub>3</sub> O <sub>2</sub>	c	-570	NaBr	c	-144	RbF·H <sub>2</sub> O	c	-100
NH <sub>4</sub> CN	c	4,200	NaBr·2H <sub>2</sub> O	c	4,454	RbF·1½H <sub>2</sub> O	c	320
NH <sub>4</sub> CNS	c	5,400	NaBrO <sub>3</sub>	c	6,430	RbCl	c	4,130
CH <sub>3</sub> NH <sub>2</sub> Cl	c	1,378	NaI	c	-1,800	RbClO <sub>3</sub>	c	11,410
(CH <sub>3</sub> ) <sub>2</sub> NHCl	c	350	NaI·2H <sub>2</sub> O	c	3,855	RbClO <sub>4</sub>	c	13,560
N(CH <sub>3</sub> ) <sub>2</sub> Cl	c	975	NaIO <sub>3</sub>	c	4,850	RbBr	c	5,230
N(CH <sub>3</sub> ) <sub>2</sub> Br	c	5,800	NaNO <sub>3</sub>	c	3,320	RbBrO <sub>3</sub>	c	11,700
N(CH <sub>3</sub> ) <sub>2</sub> I	c	10,055	NaNO <sub>3</sub>	c	4,900	RbI	c	6,000
AgClO <sub>4</sub>	c	1,760	NaC <sub>2</sub> H <sub>3</sub> O <sub>2</sub>	c	-4,140	RbNO <sub>3</sub>	c	8,720
AgNO <sub>3</sub>	c	8,830	NaC <sub>2</sub> H <sub>3</sub> O <sub>2</sub> ·3H <sub>2</sub> O	c	4,700	CaOH	c	-17,100
AgNO <sub>3</sub>	c	5,400	NaCN	c	290	CaOH·H <sub>2</sub> O	c	-4,900
LiOH	c	-5,632	NaCN·4H <sub>2</sub> O	c	790	CaF <sub>2</sub>	c	-8,810
LiOH·H <sub>2</sub> O	c	-1,600	NaCN·2H <sub>2</sub> O	c	4,440	CaF <sub>2</sub> ·H <sub>2</sub> O	c	-2,500
LiF	c	1,130	NaCNO	c	4,590	CaF <sub>2</sub> ·½H <sub>2</sub> O	c	-1,300
LiCl	c	-8,850	NaCNS	c	1,632	CaCl	c	4,250
LiCl·H <sub>2</sub> O	c	-4,580	KOH	c	-13,769	CaClO <sub>3</sub>	c	13,250
LiClO <sub>4</sub>	c	-6,345	KOH·H <sub>2</sub> O	c	-3,500	CaBr	c	6,210
LiClO <sub>4</sub> ·3H <sub>2</sub> O	c	7,795	KOH·½H <sub>2</sub> O	c	-2,500	CaBrO <sub>3</sub>	c	12,060
LiBr	c	-11,670	KF	c	-4,238	CaI	c	7,970
LiBr·H <sub>2</sub> O	c	-5,560	KF·2H <sub>2</sub> O	c	1,666	CaNO <sub>2</sub>	c	9,580

\*25 deg C = 298.15 K. One calorie (thermochemical) = 4.184 joules.

\*From: NSRDS—NBS 2, "Thermal Properties of Aqueous Uni-univalent Electrolytes", V.B. Parker, National Bureau of Standards, 1965.

cast and their ends cropped; then they are placed in a furnace and heated to a specified temperature. The heated ingot is placed in a press where it is pierced. This hollow cylinder, open at one end, is then descaled and drawn over a mandrel on a horizontal drawbench. The closed end is then burned off, and the hollow forging is chemically descaled. Following this, the forging is straightened, placed in a lathe, and the outer diameter machined to a true dimension. The inside is dressed to remove scale, but no machining is done on the inside.

**Code Designations** Appropriate ASTM specifications list the physical and chemical properties of materials used in piping systems. The complete compilation of "Steel Piping, Tubing and Fittings" can be purchased from the ASTM, 1916 Race St., Philadelphia, Pa. 19103. The treatment in this section is a brief outline of frequently encountered materials.

**Carbon-steel piping** is most frequently used as manufactured in accordance with ASTM specifications A106 and A53. The chemical composition of these two materials is identical; both are subjected to physical tests, but those for A106 are more rigorous. For example, the Code for Pressure Piping permits the use of A53 for pressures of 600 lb/in<sup>2</sup> gage (22,137 N/m<sup>2</sup>) and less but excludes its use for higher pressures; A106 can be used for pressures not above 2,500 lb/in<sup>2</sup> gage (92,237 N/m<sup>2</sup>). A53 and A106 are made in Grades A and B; Grade B has higher strength properties but is less ductile and, for this reason, Grade A is permitted only for cold bending or close coiling. When carbon steel is intended for use in welded construction at temperatures in excess of 775°F (413°C), consideration should be given to the possibility of graphite formation.

**Carbon-molybdenum steel piping** may be obtained as A204 (electric-fusion-welded), A335 (seamless) or A369 (forged, turned, and bored). This material was developed in past years when steam temperatures were approaching, but not reaching, 1000°F (538°C) under which conditions carbon steel was both unsatisfactory and uneconomical. It has been found that there is a tendency for carbon-molybdenum to show graphitization at temperatures in excess of 800°F (427°C), and its use in welded construction above this value should be with caution.<sup>1</sup>

**Chromium-molybdenum steel** has been used for temperatures up to 1100°F (593°C). In the small diameters, the material is usually available in the seamless construction; because of the inability of the seamless mills to fabricate large-diameter and heavy-walled pipe, it may be necessary to resort to the more expensive hollow-forged or forged-and-bored piping for higher pressures and temperatures. The material for a high-temperature piping system should be selected after a careful review of technical and economic considerations; the following is intended only as being indicative of recent and current practice. For temperatures up to 950°F (510°C), ½ percent Cr-½ percent Mo (A335, Grade P2) is used; for temperatures 950 to 1000°F (510 to 538°C), 1 percent Cr-½ percent Mo (A335, Grade P12) is used; for temperatures 1000 to 1050°F (538 to 566°C), 1¼ percent Cr-½ percent Mo (A335, Grade P11) may be used; for temperatures 1050 to 1100°F (566 to 593°C), 2¼ percent Cr-1 percent Mo (A335, Grade P22) is frequently used. When there is a combination of high temperatures and erosive action, 5 percent Cr-½ percent Mo (A335, Grade 5) has been found desirable.

<sup>1</sup>Modern steel-making practices have reduced significantly the problem of graphitization. However, in pipe installed in the 1940s and early 1950s, there have been many failures.

**Stainless-steel piping** is available in a variety of compositions, most popular of which are ASTM A213, Grade TP321 (16 percent Cr-8 percent Ni, stabilized with titanium) and ASTM A213, Grade TP347 (18 percent Cr-8 percent Ni, stabilized with columbium). Either of these two materials may be used up to 1200°F (649°C); particular care must be given to choice of welding rod to avoid brittleness in the welds.

Refer to Tables 1 and 2, respectively, for permissible stress values for piping materials at low and elevated temperatures.

**Schedule Designations** Many years ago piping was designated as standard, extra-strong, and double extra-strong. There was no provision for thin-walled pipe, and no intervening standard thicknesses between the three schedules, which covered too great a spread to be economical without intermediate weights. Table 3 lists piping as a function of the schedule number which is given, approximately, by the following relationship: Schedule no. = 1,000 ×  $P/SE$ , where  $P$  is operating pressure, lb/in<sup>2</sup> gage, and  $SE$  is allowable stress range multiplied by joint efficiency, lb/in<sup>2</sup>.

**EXAMPLE.** Find the required schedule of ASTM A106 Grade B pipe operating at 1,150 lb/in<sup>2</sup> gage and 600°F.

Table 2 lists  $SE$  value as 15,000 lb/in<sup>2</sup>. Substituting,  $1,000 (1,150/15,000) = 76.6$ . Use schedule no. 80, tentatively, but check with Eq. (1), below.

Commercial sizes of wrought-iron and steel pipe are known by their nominal inside diameter (ID) from ⅜ (0.3175 cm) to 12 in (30.5 cm). Above 12 in ID, pipe is usually known by its outside diameter (OD). All classes of pipe of a given nominal size have the same OD, the extra thickness for different weights being on the inside.

**Thickness of Pipe** The following notes, covering power piping systems, have been abstracted from Part 2 of the Code for Power Piping (ANSI B31.1-1967).

For inspection purposes, the minimum thickness of pipe wall to be used for piping at different pressures and for temperatures not exceeding those for the various materials listed in Tables 1 and 2 shall be determined by the formula

$$t_m = \frac{PD}{2(SE + P_y)} + A \quad (1)$$

where  $t_m$  = minimum pipe-wall thickness, in, allowable on inspection;  $P$  = maximum internal service pressure, lb/in<sup>2</sup> gage (plus water-hammer allowance in case of cast-iron conveying liquids);  $D$  = OD of pipe, in;  $SE$  = maximum allowable stress in material due to internal pressure and joint efficiency, at the design temperature, lb/in<sup>2</sup>; values of  $SE$  given in Tables 1 and 2 include allowance for joint efficiency;  $y$  = a coefficient, values for which are listed in Table 4;  $A$  = allowance for threading, mechanical strength, and corrosion, in, with values of  $A$  listed in Table 5.

The thickness of cast-iron pipe conveying liquid may be taken from Table 14, using the pressure class next higher than the maximum internal service pressure in pounds per square inch. Where cast-iron pipe is used for steam service, the thickness should be calculated by Eq. (1), using  $SE$  values listed in Table 1.

Plain-end pipe includes pipe joined by flared compression couplings, lapped joints, and by welding, i.e., by any method that does not reduce the wall thickness of the pipe at the joint.

**Physical and Chemical Properties of Pipes, Tubes, Etc.** The design of piping for operation above 750°F (399°C) presents many problems not encountered at lower temperatures.

Table 2. Allowable Stress Values for Temperatures 550 to 1200°F (343.4 to 649°C) (Continued)

ASTM spec. No.	Grade	Nominal composition	Spec. min tensile	Longitudinal joint efficiency factor	$P$ , psi <sup>a</sup>	650°	700°
Automatically welded austenitic steel, A312	TP304H	18Cr-8Ni <sup>b</sup>	75,000	0.85	8	12,050	
	TP304H	18Cr-8Ni <sup>b</sup>	75,000	0.85	8	8,900	
	TP316H	18Cr-10Ni-16Cr <sup>b</sup>	75,000	0.85	8	13,600	
	TP316H	18Cr-10Ni-16Cr <sup>b</sup>	75,000	0.85	8	9,600	
	TP316H	18Cr-10Ni-16Cr <sup>b</sup>	75,000	0.85	8	12,850	
	TP316H	18Cr-10Ni-16Cr <sup>b</sup>	75,000	0.85	8	10,350	
Seamless A53 carbon steel	A <sup>c</sup>		48,000	1.00	1	12,000	11,650
	B <sup>d</sup>		60,000	1.00	1	15,000	14,350
	A <sup>c</sup>		48,000	1.00	1	12,000	11,650
	B <sup>d</sup>		60,000	1.00	1	15,000	14,350
A106 carbon steel	B <sup>d</sup>		60,000	1.00	1	17,500	16,600
	C <sup>e</sup>		70,000	1.00	1		

The stress values calculated include a longitudinal joint efficiency factor where applicable.

The stress values in this table may be interpolated to determine values for intermediate temperatures. Materials listed in Table 1 of the ASME Boiler and Pressure Vessel Code are not tabulated in this table. Allowable stresses for such materials shall be taken from Sections I and VIII of the ASME Boiler and Pressure Vessel Code.

<sup>a</sup>The grouping of materials as to  $P$  number classification is made on the basis of hardenability characteristics. The  $P$  numbers indicated in this table are identical to those adopted by the ASME Boiler and Pressure Vessel Code. Qualification of welding procedures, welders, and welding operators is required and should comply with the ASME Boiler and Pressure Vessel Code (Section IX) except as modified by Part 1225.

<sup>b</sup>The severity and grades of material tabulated should not be used at temperatures in excess of the maximum temperatures for which the allowable stress values are indicated.

<sup>c</sup>For stress values below 650°F, which are not tabulated in Table 1, refer to Section I, Table 1A, of the ASME Boiler and Pressure Vessel Code.

<sup>d</sup>Upon prolonged exposure to temperatures above about 575°F, the carbide phase of carbon steel may be converted to graphite.

<sup>e</sup>Upon prolonged exposure to temperatures above about 850°F, the carbide phase of carbon-manganese steel may be converted to graphite.

<sup>f</sup>Upon prolonged exposure to temperatures above about 975°F, the carbide phase of chromium-manganese steel (with chromium under 0.60) may be converted to graphite.

<sup>g</sup>At temperatures over 1000°F, these stress values apply only when the carbon is 0.04 percent or higher.

<sup>h</sup>In size 8 in. and larger and schedule 140 or heavier, the minimum tensile strength may be 70,000 lb/in<sup>2</sup>. In these sizes and thicknesses, the indicated allowable stress values should be reduced by the ratio of 70 divided by 75.

<sup>i</sup>For allowable stress values below 700°F, see Table 1.

<sup>j</sup>The values tabulated apply to factory quality material.

<sup>k</sup>Because of the relatively low yield strength of these materials, these higher stress values were established at temperatures where the short-time tensile properties govern to permit the use of these values where slightly greater deformation is acceptable. The stress values in this range exceed 62½ percent but do not exceed 90 percent of the yield strength at temperature. Use of these stresses may result in dimensional changes due to permanent strain. These stress values are not recommended for the flanges of gasketed joints or other applications where slight amounts of distortion can cause leakage or malfunction.

For the properties of steel applicable to high-temperature service (as well as to ordinary service) for pipes, tubes, fittings, bolting material, etc., see Sec. 6. For a discussion of creep properties, see Sec. 5.

Piping of thickness designed in accordance with Eq. (1) may be used for any combination of pressure and temperature for which SE values are listed in Tables 1 and 2. The following summarizes piping industry practice.

**Steam Pressures above 250 (9,224 N/m<sup>2</sup>) and not above 2,500 lb/in<sup>2</sup> (92,237 N/m<sup>2</sup>) Temperatures not above 1100°F (593°C)** For pressures in excess of 100 lb/in<sup>2</sup> (3,690 N/m<sup>2</sup>), the pipe may be seamless steel (A106), (A312), (A335), or (A376); or electric-fusion-welded steel (A155); or forged-and-bored steel (A369); or automatic-welded steel (A312). For pressures between 250 and 600 lb/in<sup>2</sup> (9,224 and 22,137 N/m<sup>2</sup>) the pipe may be seamless steel (A106) or (A53); electric-fusion-welded steel (A155); electric-resistance-welded steel (A135) or (A53). For pressures of 250 lb/in<sup>2</sup> (9,224 N/m<sup>2</sup>) and lower and for service up to 750°F (399°C), any of the following may be used: electric-fusion-welded steel (A134) or (A139); electric-resistance-

**Temperature not above 450°F (232°C)** Pipe may be electric-fusion-welded steel (A134 or A139), electric-resistance-welded steel (A135), seamless or welded steel (A53), or wrought iron (A72). Copper and brass may be used if the temperature does not exceed 406°F. Cast iron may also be used. For close coiling or cold bending, Grade A seamless steel (A53); or Grade A electric-welded steel (A53), (A135), or (A139) is suitable. Pipe permissible for this service may be used for temperatures above 450°F (232°C) if the proper SE is used in calculating the pipe-wall thickness.

Valves below 3 in. may have inside stem screws. Stop valves 8 in. and over must be bypassed. Bodies, bonnets, and yokes are of cast iron, malleable iron, steel, bronze, brass, or Monel. Flanged-steel fittings must conform to the 300 lb ANSI Standard B16.5, if of cast iron, to the 250 lb ANSI Standard B16.2; or, for screwed fittings, to the ANSI Standard B16.4. Malleable-iron screwed fittings must conform to the 300 lb MSS SP-31 specifications, except that the 150 lb ANSI Standard B16.3 may be used for pressures not greater than 150 lb. Welded fittings may be used.

**Steam Pressures from 25 to 125 lb/in<sup>2</sup>, Temperatures not above 450°F** Pipe may be of steel, wrought iron, cast iron, copper, or brass; valve bodies of cast iron, malleable iron, steel, or brass. Fittings are of 125 lb or 150 lb American Standard cast iron with screwed or flanged ends, or of malleable iron with screwed ends.

**Steam Pressures 25 lb/in<sup>2</sup> and less, Temperature up to 450°F** Pipe may be of steel, wrought iron, spiral-ribbed steel, brass, copper, or cast iron. Flanged fittings conform to the 25 lb ANSI Standard B16.2. Screwed fittings are of the 125 lb ANSI Standard B16.4 or of the 150 lb ANSI Standard B16.3 for cast iron or malleable iron, respectively, or the B16.15 for bronze. Welded fittings may be used.

Pipe coils are made from any of the commercial sizes of iron, steel, brass, and copper pipe and tubing. Limiting center-to-center dimensions, to which pipe coils can be fabricated in sizes ¾ to 2 in., are given in Table 10. Steel tubing cannot be bent to the absolute limits of brass or copper.

Seamless mechanical tubing is obtainable in outside diameters ranging from ¼ to 10 ¾ in. in wall thickness from 20 gage to 2 in. (0.091 to 5.08 cm), and in standard pipe weights and

**Table 1. Allowable Stress Values for Temperatures up to 650°F (343.4°C)**  
(ANSI B36.1.0—1967)

Max allowable stress value, lb/in. <sup>2</sup> , for metal temperatures not exceeding °F													
ASTM spec. No.	Grade	Nominal composition	Spec. min tensile	Longitudinal joint efficiency factor	P No. <sup>a</sup>	Max allowable stress value, lb/in. <sup>2</sup> , for metal temperatures not exceeding °F							
						-20 to 100	200	300	400 <sup>c</sup>	450	500	600	650
Pipe: Welded carbon steel, butt-welded A120, Lap-welded A120, Automatically welded austenitic steel, A312	TP304H <sup>a</sup>	18Cr-8Ni	75,000	0.85	1	6,500	6,350	6,100	5,850	5,700	12,350	12,200	12,150
	TP304H <sup>a</sup>	18Cr-8Ni	75,000	0.85	1	8,800	8,600	8,200	7,800	7,600	9,700	9,200	9,050
	TP316H <sup>a</sup>	18Cr-12Ni-Mo	75,000	0.85	8	15,950	14,050	13,200	12,700		12,350	12,200	12,150
	TP316H <sup>a</sup>	18Cr-12Ni-Mo	75,000	0.85	8	15,950	13,600	14,350	10,400		9,700	13,600	13,600
	TP316H <sup>a</sup>	18Cr-12Ni-Mo	75,000	0.85	8	15,950	14,850	14,350	13,850		10,700	10,100	9,850
	TP316H <sup>a</sup>	18Cr-12Ni-Mo	75,000	0.85	8	15,950	13,700	12,400	11,450		10,700	10,100	9,850
	TP321H <sup>a</sup>	18Cr-10Ni-Ti	75,000	0.85	8	15,950	14,300	13,450	13,100		12,850	12,850	12,850
	TP321H <sup>a</sup>	18Cr-10Ni-Ti	75,000	0.85	8	15,950	14,300	13,450	13,100		12,850	12,850	12,850
	TP321H <sup>a</sup>	18Cr-10Ni-Ti	75,000	0.85	8	15,950	14,050	13,000	12,300		11,450	10,900	10,600
	TP321H <sup>a</sup>	18Cr-10Ni-Ti	75,000	0.85	8	15,950	14,050	13,000	12,300		11,450	10,900	10,600
Electric-fusion- welded austenitic steel, A358 Class I <sup>a</sup>	TP304	18Cr-8Ni	75,000	1.00	8	18,750	16,550	15,550	14,950		14,550	14,350	14,300
	TP304	18Cr-8Ni	75,000	1.00	8	18,750	16,000	13,750	12,250		11,400	10,800	10,650
	TP304	18Cr-8Ni	75,000	0.90	8	16,900	14,400	14,000	13,450		13,100	12,900	12,900
	TP304	18Cr-8Ni	75,000	0.90	8	16,900	14,400	12,400	11,000		10,250	9,700	9,600
	TP316	18Cr-12Ni-Mo	75,000	1.00	8	18,750	16,900	16,900	16,300		16,000	16,000	16,000
	TP316	18Cr-12Ni-Mo	75,000	1.00	8	18,750	16,100	14,600	13,500		12,600	11,900	11,600
	TP316	18Cr-12Ni-Mo	75,000	1.00	8	18,750	15,750	14,700	14,000		14,400	14,400	14,400
	TP316	18Cr-12Ni-Mo	75,000	0.90	8	16,900	14,500	13,150	12,150		11,350	10,700	10,450
	TP316	18Cr-12Ni-Mo	75,000	0.90	8	16,900	14,500	13,150	12,150		11,350	10,700	10,450
	TP321	18Cr-10Ni-Ti	75,000	1.00	8	18,750	16,800	15,850	15,400		15,100	15,100	15,100
Seamless: A120 carbon steel A335 ferritic alloy <sup>a</sup> A335 ferritic alloy <sup>a</sup> A369 ferritic alloy <sup>a</sup> A312, Austenitic <sup>a</sup> Austenitic <sup>a</sup> Austenitic <sup>a</sup> Austenitic <sup>a</sup> Austenitic <sup>a</sup> A376 Austenitic <sup>a</sup> Austenitic <sup>a</sup> Austenitic <sup>a</sup> Austenitic <sup>a</sup> A340 Austenitic <sup>a</sup> Austenitic <sup>a</sup> Austenitic <sup>a</sup> Austenitic <sup>a</sup>	P5	5Cr-15Mo	60,000	1.00	1	10,800	10,600	10,200	9,800	9,600	14,500	14,000	13,700
	P5b	5Cr-15Mo-Si	60,000	1.00	5	15,000	15,000	15,000	15,000		14,500	14,000	13,700
	TP5	5Cr-15Mo	60,000	1.00	5	15,000	15,000	15,000	15,000		14,500	14,000	13,700
	TP304H	18Cr-8Ni	75,000	1.00	8	18,750	16,550	15,550	14,950		14,550	14,350	14,300
	TP304H	18Cr-8Ni	75,000	1.00	8	18,750	16,000	13,750	12,250		11,400	10,800	10,650
	TP316H	18Cr-12Ni-Mo	75,000	1.00	8	18,750	16,900	16,900	16,300		16,000	16,000	16,000
	TP316H	18Cr-12Ni-Mo	75,000	1.00	8	18,750	16,100	14,600	13,500		12,600	11,900	11,600
	TP316H	18Cr-12Ni-Mo	75,000	1.00	8	18,750	16,000	14,600	13,500		12,600	11,900	11,600
	TP321H	18Cr-10Ni-Ti	75,000	1.00	8	18,750	16,550	15,300	14,450		13,500	12,800	12,500
	TP321H	18Cr-10Ni-Ti	75,000	1.00	8	18,750	16,550	15,300	14,450		13,500	12,800	12,500
A376 Austenitic <sup>a</sup> Austenitic <sup>a</sup> Austenitic <sup>a</sup> Austenitic <sup>a</sup> Austenitic <sup>a</sup> A340 Austenitic <sup>a</sup> Austenitic <sup>a</sup> Austenitic <sup>a</sup> Austenitic <sup>a</sup> Austenitic <sup>a</sup>	TP304H	18Cr-8Ni	75,000	1.00	8	18,750	16,550	15,550	14,950		14,550	14,350	14,300
	TP304H	18Cr-8Ni	75,000	1.00	8	18,750	16,000	13,750	12,250		11,400	10,800	10,650
	TP316H	18Cr-12Ni-Mo	75,000	1.00	8	18,750	16,800	15,850	15,400		15,100	15,100	15,100
	TP316H	18Cr-12Ni-Mo	75,000	1.00	8	18,750	16,550	15,300	14,450		13,500	12,800	12,500
	TP316H	18Cr-12Ni-Mo	75,000	1.00	8	18,750	16,550	15,300	14,450		13,500	12,800	12,500
	TP321H	18Cr-10Ni-Ti	75,000	1.00	8	18,750	16,550	15,300	14,450		13,500	12,800	12,500
	TP321H	18Cr-10Ni-Ti	75,000	1.00	8	18,750	16,550	15,300	14,450		13,500	12,800	12,500
	TP321H	18Cr-10Ni-Ti	75,000	1.00	8	18,750	16,550	15,300	14,450		13,500	12,800	12,500
	TP321H	18Cr-10Ni-Ti	75,000	1.00	8	18,750	16,550	15,300	14,450		13,500	12,800	12,500
	TP321H	18Cr-10Ni-Ti	75,000	1.00	8	18,750	16,550	15,300	14,450		13,500	12,800	12,500
A340 Austenitic <sup>a</sup> Austenitic <sup>a</sup> Austenitic <sup>a</sup> Austenitic <sup>a</sup> Austenitic <sup>a</sup> Austenitic <sup>a</sup> Austenitic <sup>a</sup> Austenitic <sup>a</sup> Austenitic <sup>a</sup> Austenitic <sup>a</sup>	FP304H	18Cr-8Ni	70,000	1.00	8	17,500	15,450	14,500	13,750		14,950	14,950	14,950
	FP304H	18Cr-8Ni	70,000	1.00	8	17,500	15,450	14,500	13,750		14,950	14,950	14,950
	FP316H	18Cr-12Ni-Mo	70,000	1.00	8	17,500	16,100	14,600	13,500		12,600	11,900	11,600
	FP316H	18Cr-12Ni-Mo	70,000	1.00	8	17,500	16,100	14,600	13,500		12,600	11,900	11,600
	FP316H	18Cr-12Ni-Mo	70,000	1.00	8	17,500	16,100	14,600	13,500		12,600	11,900	11,600
	FP321H	18Cr-10Ni-Ti	70,000	1.00	8	17,500	15,450	14,500	13,750		14,950	14,950	14,950
	FP321H	18Cr-10Ni-Ti	70,000	1.00	8	17,500	15,450	14,500	13,750		14,950	14,950	14,950
	FP321H	18Cr-10Ni-Ti	70,000	1.00	8	17,500	15,450	14,500	13,750		14,950	14,950	14,950
	FP321H	18Cr-10Ni-Ti	70,000	1.00	8	17,500	15,450	14,500	13,750		14,950	14,950	14,950
	FP321H	18Cr-10Ni-Ti	70,000	1.00	8	17,500	15,450	14,500	13,750		14,950	14,950	14,950

**PROBABLE  
COST  
DEVELOPMENT**



# COST ESTIMATE ANALYSIS

INVOICE NO. / CONTRACT NO.										EFFECTIVE PRICING DATE		DATE PREPARED	
PROJECT HOLSTON AAP AREA B N17 R10 A12										DRAWING NO.		SHT OF	
LOCATION KINGSPORT, TENN.										ESTIMATOR PDL		CHECKED BY	
<input type="checkbox"/> CODE A <input type="checkbox"/> CODE B <input type="checkbox"/> CODE C <input type="checkbox"/> OTHER													
TASK DESCRIPTION	QUANTITY		LABOR		EQUIPMENT		MATERIAL		TOTAL		SHIPPING		
	No. of Units	Unit Meas	MH	Unit Price	Total Hrs	Unit Price	Cost	Unit Price	Cost	Unit Price	Unit WT	Total WT	
ECO No. 1													
57821 PIPING:													
6" SCH. 40 UNDER.	250	LF		16.55			4138	1.28	320	31		12208	
3" SCH. 40 UNDER	250	LF		17.62			4413	1.28	320	19.50		9608	
4" SCH. 40	150	LF		11.70			1755	1.40	210	10.00		3555	
2" SCH. 40	150	LF		7.25			1163	.82	129	5.52		2129	
PIPE INSUL.	300	LF					2000					3000	
TURBINE MOUNTING		LS					10000					20000	
15000# HR STAL. SURF. COAT		GA					10000		2500			42500	
COND. PUMP	1	GA					300					1800	
8" CONDENS. UNDER PIPING	300	LF		23			6900	1.81	543	31		16743	
PIPE FITS & MISCS.	1	LOT					10000					35000	
							50669		4022			146543	
TOTAL THIS SHEET													



# COST ESTIMATE ANALYSIS

INVOICE NO./CONTRACT NO.										EFFECTIVE PRICING DATE		DATE PREPARED	
PROJECT HOUSTON AIR ARMS ACRO										DRAWING NO.		SHT OF	
LOCATION KINGSFORD TANK										ESTIMATOR PDL		CHECKED BY	
<input type="checkbox"/> CODE A <input type="checkbox"/> CODE B <input type="checkbox"/> CODE C <input type="checkbox"/> OTHER													
TASK DESCRIPTION		QUANTITY		LABOR		EQUIPMENT		MATERIAL		TOTAL		SHIPPING	
No. of Units	Unit Meas	MH/Unit	Total Hrs	Unit Price	Cost	Unit Price	Cost	Unit Price	Cost	Unit Price	Cost	Unit WT	Total WT
STEAM PIPING													
250	LF			17.42	4350	1.28	320	33.50	8375		13045		
250	LF			17.68	4413	1.28	320	19.50	4875		9608		
150	LF			2.3	3430	1.81	272	5.1	4650		8372		
150	LF			7.25	1163	.86	129	5.50	837		2129		
1	LOT				2500				1200		3700		
LAWRENCE PIPE :													
200	LF			9.20	1840	1.12	224	6.40	1280		3344		
1	LOT				2000				1000		3000		
HI TEMP PUMP (CROSSING)													
1	EA				300				3438		3738		
1	EA				210				1375		1591		
1	EA				250				1000		1250		
UNFIRED BUR. VALVE													
1	EA				5000		2500		75000		82500		
MISC. ACCESS. & FIXES													
1	LOT				20000				40000		60000		
					45482		3165		113030		192277		
TOTAL THIS SHEET													

## INVOICE NO. / CONTRACT NO.:

## EFFECTIVE PRICING

DATE PREPARED:

\_\_\_\_\_

PROJECT

LOCATION

☐ CODE A☐ OTHER

☐ CODE C

---

DRAWING NO.

ESTIMATOR

SHT OF

CHECKED BY

[illegible]

# COST ESTIMATE ANALYSIS

PROJECT <u>HOLSTEN AAP AREA B NITRIC ACID</u>										INVT. NO. / CONTRACT NO.		EFFECTIVE PRICING DATE		DATE PREPARED	
LOCATION <u>KINGSFORD TERN</u>										<input type="checkbox"/> CODE A <input type="checkbox"/> CODE B <input type="checkbox"/> CODE C <input type="checkbox"/> OTHER		DRAWING NO.		SHT OF	
												ESTIMATOR <u>ADL</u>		CHECKED BY	
TASK DESCRIPTION	QUANTITY		LABOR		EQUIPMENT		MATERIAL		TOTAL		SHIPPING				
	No. of Units	Unit Meas	MH / Unit	Total Hrs	Unit Price	Cost	Unit Price	Cost	Unit Price	Cost	Unit WT	Total WT			
<u>INSULATIONS ECO #4</u>															
<u>1" CALCIUM SILICATE:</u>															
18" AIR PRNTR.	12	LF			5.40	64.80			9.35	112.20		177 -			
18" TAILGAS HTR.	25	LF			5.40	135 -			9.35	233.75		368.75			
8" TEGS. PIPE TO TURB.	120	LF			3.84	460.80			4.26	511.20		972 -			
<u>0.010 S.S. JACKET:</u>															
18" AIR PRNTR	60	SF			4.05	241.80			9.3	55.80		297.60			
18" TAILGAS HTR	125	SF			4.05	503.75			9.3	116.25		620 -			
8" TEGS. PIPE TO TURB.	315	SF			4.05	1269.45			9.3	292.95		1562.40			
<u>18" FLANGE SETS (NEAR)</u>															
18" FL. SETS (JACKET)	10	SF			13.45	134.50			2.71	27.10		161.60			
<u>SUBTOTAL</u>															
<u>15% CONTING.</u>															
<u>TOTAL CONET. - 450</u>															
<u>TOTAL THIS SHEET</u>															



[illegible]



AFFILIATED ENGINEERS SE, INC.  
3300 SW Archer Road  
Gainesville, Florida 32608  
(904) 376-5500  
FAX (904) 375-3479

Made By:

PDL

Date:

12-22-95

Job No:

95094-00

Checked By:

Date:

Sheet No:

of

Calculations For:

ECO #7 COSTS

### ASSUMPTIONS

- ① COST OF ST. STL. FABRICATION IS PROPORTIONAL TO PUBLISHED COST MULTIPLIER FOR 90° PIPE ELBOW FROM MOANS:

SCH. 40 12"  $\phi$  316 SS 90° ELBOW - \$1720 MATERIAL

SCH 40 12"  $\phi$  BL. IRON 90° ELBOW - \$212 MATERIAL

$$\text{MULTIPLIER} = \frac{1720}{212} = 8.1$$

- ② PUMP AND ACCUMULATOR SKIDS AND BACK PRESSURE REGULATOR INCLUDED IN CLAYTON QUOTATION WILL SERVE BOTH GENERATORS

- ③ STANDARD GENERATOR COST IS 1/3 OF TOTAL QUOTED COST.

ADDED COST FOR ST. STL. GENERATOR WHICH CLAYTON DECLINED TO QUOTE:

$$\text{COST} = \frac{\$68600}{3} (8.1) = \$185522$$



P.O. BOX 5530, EL MONTE, CALIFORNIA 91734-1530

TEL (818) 443-9381 FAX (818) 442-1701

QUOTATION No. G-11623

TO: Affiliated Engineers SE, Inc.  
3300 SW Archer Road  
Gainesville, Florida 32608-1731

TERMS: 20% with Order-Balance Net 30  
Subject to Credit Approval

ATTN: Paul Little  
(904) 376-5500 -TEL  
(904) 375-3479 -FAX

FOB: El Monte, CA - Prepay and Add  
APPROX. SHIP DATE: 120 Days  
AFTER RECEIPT AND ACCEPTANCE OF ORDER

RE: Clayton Steam Generator

QUANT.	MODEL AND SPECIFICATIONS	UNIT PRICE	TOTAL
1	<b>EGSG-5ECO201 Exhaust Gas Steam Generator</b> Mono-coil, smooth tube, single pass Steam Generator Designed to maintain feedwater inlet temperature to prevent dewpoint corrosion while maintaining High efficiency.  <b>Conditions</b> Gas Flow: 20,000 lb/h T gas in: 495 °F T gas out: 266 °F Gas Press Drop: 17.4 inW.C. Steam Flow: 1,180 pph Steam Press: 80 psig		
1	<b>Bottom Inlet/Top Outlet Cones</b> Provide transition pieces from 32 inch O.D. exhaust stack to the EGSG. Includes Soot Blower Ring on Inlet Side.		
1	<b>Pump &amp; Accumulator Skids</b> Includes the following items mounted on a skid: 1 Feed Pump & Electric Motor Accumulator with Level Control & Pressure Gauge Control Box Including Starter for Clayton Pump Safety Valve(s) Overflow Steam Trap Necessary piping and wiring within skid boundary		
1	<b>Back Pressure Regulator.</b> For stabilizing steam system during load fluctuation and operation start-up.		
	<b>TOTAL: HEAT RECOVERY SYSTEM</b>		<b>\$68,610</b>
	<b>NOTE: Freight, Sales Tax, and other fees may apply.</b>		

THIS QUOTATION EXPIRES in 30 Days AND IS SUBJECT TO THE TERMS AND CONDITIONS ON THE FACE AND THE REVERSE SIDE HEREOF. PARAGRAPH 17 OF SUCH TERMS AND CONDITIONS LIMITS ACCEPTANCE OF THIS QUOTATION TO THE TERMS CONTAINED HEREIN, EXCLUDES ANY ADDITIONAL TERMS PROPOSED BY PURCHASER, AND PROVIDES THAT ANY ORDER BY PURCHASER BASED ON THIS QUOTATION (OR ACCEPTANCE BY PURCHASER OF THE GOODS DESCRIBED HEREIN) SHALL CONSTITUTE AN UNCONDITIONAL ACCEPTANCE BY PURCHASER OF EACH AND ALL OF THE TERMS AND CONDITIONS CONTAINED HEREIN, AND A WAIVER BY PURCHASER OF ANY CONFLICTING OR ADDITIONAL PROVISIONS CONTAINED IN ANY OF PURCHASERS DOCUMENTS RELATING TO THIS TRANSACTION.

**ACCEPTANCE**

THIS QUOTATION IS ACCEPTED

SUBMITTED BY

*Nick LeJeune*

Nick LeJeune - Sales Engineer - 12/22/95

*C. M.*

BY \_\_\_\_\_  
NAME TITLE DATE

SIGNATURE TITLE DATE

## Telephone Conversation



Affiliated Engineers SE, Inc.  
3300 SW Archer Road  
Gainesville, FL 32608

Conversation With NICK LEJUNO  
CLAYTON  
Representing HOLSTON AAP NITRIC ACID FAC.  
Project Name KINGS PORT, TENN.  
Location \_\_\_\_\_

Routing 95094-00  
Project Number 12-22-95  
Date \_\_\_\_\_  
Time \_\_\_\_\_

FAXED ONE PAGE QUOTE.

CLAYTON DECLINED TO QUOTE THE  
STAINLESS STEEL SECTION BECAUSE OF THE  
NITRIC ACID FORMED.

By: Paul D. Little





Affiliated Engineers SE, Inc.  
3300 SW Archer Road  
Gainesville, Florida 32608-1731

FAXED

(904)376-5500 - Office  
(904)375-3479 - Fax

## FAX TRANSMISSION COVER SHEET

TO:	NICK LOJUNO <sup>770-957-2200</sup>	FAX #:	770 907-0548
COMPANY:	CLAYTON INDUSTRIES	PROJECT #:	95094-00
FROM:	PAUL LITTLE	PAGES:	3 (incl cover sheet)
DATE-TIME:	12-11-95	Hard Copy to Follow:	NO

### REMARKS:

DESIRE BUDGET PRICING &  
NOMINAL PERFORMANCE THAT MIGHT  
BE EXPECTED. I ANTICIPATE EACH  
UNIT WILL PRODUCE IN EXCESS OF  
1000 #/HR SATURATED STEAM.

**CLAYTON INDUSTRIES  
HEAT RECOVERY SYSTEM  
FACT SHEET FOR QUOTATION**

(Designed for initial proposal only to establish  
size and budget estimate for basic equipment)

DATE 12-11-95

COMPANY: ABSB

ADDRESS: GAINESVILLE, FL.

NAME OF CONTACT: PAUL LITTLE

PRODUCT GAS UNIT

Gas Flow Mass Units 17650

Standard Volume Units (at 75 °F or 24 °C)

Gas Inlet Temperature

Steam Pressure

Receiver (Feedwater) Temp. (usually 200 °F or 93 °C)

OPTION\* 1. Gas Outlet Temperature

2. Total Heat Transfer

3. Steam Mass Flow Rate

\*(Indicate "maximum available" if unknown)

Allowable Gas Pressure Drop

Circle appropriate units of measure

17650 (lbs/hr or Kg/hr)

(SCFM or SM<sup>3</sup>/hr)

350 (F or C)

80 (Psi or bar)

150 (F or C)

(F or C)

(Btu/hr or Kcal/hr)

(lbs/hr or k/hr)

27 (In W.C. or mm -  
N.C.)

DEW POINT = 255 °F  $C_p = 0.253 \frac{Btu}{lb \cdot ^\circ F}$

Waste Gas Properties: PERCENT BY VOLUME: N<sub>2</sub> - 71.3; NO<sub>2</sub> - 11.5%; H<sub>2</sub>O - 16.4%

Source of Waste Gas (Incinerator, oven, turbine, engine, etc.): CHEMICAL PROCESS

Source of Fuel (gas, diesel oil, commercial waste, etc.): NA

Specific Gravity<sup>1</sup> \_\_\_\_\_ Temp. \_\_\_\_\_ Specific Heat<sup>2</sup> \_\_\_\_\_ Temp. \_\_\_\_\_

Indicate utilization factor, (8 hours/day, 5 days/week; or 24 hrs/day,

Continuous; standby only, etc.): 24 HRS/DAY

Equipment estimate at job site (size and number of sections): \_\_\_\_\_

Equipment selection Clayton Engineering: \_\_\_\_\_

<sup>1</sup>Will use the following figures if not available: 1.0 @ 70 °F.

<sup>2</sup>Will use the following figures if not available: 25 @ 800 °F.

REQUIRES 400 SERIES  
STAINLESS STEEL GAS  
SIDE CONSTRUCTION. CONDENS-  
ATION IS DESIRABLE - NITRIC  
ACID WILL BE THE RESULT.

**CLAYTON INDUSTRIES  
HEAT RECOVERY SYSTEM  
FACT SHEET FOR QUOTATION**

(Designed for initial proposal only to establish  
size and budget estimate for basic equipment)

DATE 12-11-85

COMPANY: AESB

ADDRESS: GAINESVILLE, FL.

NAME OF CONTACT: PAUL LITTLE

TURBINE EXHAUST UNIT

Gas Flow Mass Units 20000 #/HR

Standard Volume Units (at 75°F or 24°C)

Gas Inlet Temperature 495°F

Steam Pressure 80 PSIG

Receiver (Feedwater) Temp. (usually 200°F or 93°C)

OPTION\* 1. Gas Outlet Temperature

2. Total Heat Transfer

3. Steam Mass Flow Rate

\* (Indicate "maximum available" if unknown)

Wearable Gas Pressure Drop

Circle appropriate units of measure

20000 (lbs/hr or Kg/hr)

\_\_\_\_ (SCFM or SM<sup>3</sup>/hr)

495 (F or C)

80 (Psi or bar)

150 (F or C)

\_\_\_\_ (F or C)

\_\_\_\_ (Btu/hr or Kcal/hr)

\_\_\_\_ (lbs/hr or k/hr)

27 (In W.C. or mm -  
N.C.)

Waste Gas Properties: PERCENT BY VOLUME: N<sub>2</sub>-80.2; NO-4.9%; H<sub>2</sub>O-13.9%

Source of Waste Gas (Incinerator, oven, turbine, engine, etc.): CP=0.263 B/#°F

Source of Fuel (gas, diesel oil, commercial waste, etc.): N.A.

Specific Gravity<sup>1</sup> \_\_\_\_\_ Temp. \_\_\_\_\_ Specific Heat<sup>2</sup> \_\_\_\_\_ Temp. \_\_\_\_\_

Indicate utilization factor, (8 hours/day, 5 days/week; or 24 hrs/day,

Continuous; standby only, etc.): 24 HR/DAY

Equipment estimate at job site (size and number of sections): \_\_\_\_\_

Equipment selection Clayton Engineering: \_\_\_\_\_

<sup>1</sup>Will use the following figures if not available: 1.0 @ 70°F.

<sup>2</sup>Will use the following figures if not available: .25 @ 800°F.

ENERGY  
RATE  
SOURCE  
MATERIAL

J. Bauckellon, PE  
3/95  
REC'D FROM  
J. Bauckellon  
7/16/95  
RS

1994 OUT-OF-POCKET COST FOR STEAM, B-200  
GIVEN: 1994 AREA B MONTHLY USAGE & PROD. REPORT, BY KEN HARRIS

Sum of individual boilers steam output = 1,324,620,000 lbs

Building Steam Output = Sum - internal consumption (turbines, DA, etc)  
= 1,324,620,000 × .836 = 1,107,382,000 lbs  
= 1.107 m Btu  
16.4% (EEAD study, EMC Engineering, 1992, p. C-4)

Steam Coal, 1994 = 64,673 tons

Btu content of coal = 64,673 tons × 2000 × 14,100  $\frac{\text{Btu}}{\text{lb}}$   
= 1.824 m m Btu  
(Per HOC coal purch spec June 1994)

Cost of treatment of Sulfuric System backwash water =

50 gpm ave × 60  $\frac{\text{min}}{\text{hr}}$  × 8760 × \$.239  $\frac{\text{Utilities Cost Report}}{1000 \text{ gal}} = \$6,500/\text{yr.}$

COST of Filter Water for feed water =

$\frac{1,324,620,000 \text{ lbs} \times \$0.148}{8 \text{ lbs water} \times 1000 \text{ gal}} = \$24,500/\text{yr}$   
Utilities Cost Report

Cost of electricity (motors, precipitators etc) =

412,000  $\frac{\text{KWH (ave)}}{\text{mo}}$  × .035  $\frac{\text{Cost of elec 2235}}{\text{KWH}} \times 12 \text{ mo} = \$173,000/\text{yr}$   
Per Mar '95 elec bill

Cost of fly ash disposal = 15,000 est

Cost of cinder removal = 10,000 est

[Cost of bldg maintenance = \$393,391 routine + \$529,104 major = \$922,465]

COST of water treatment chemicals (See Osmosis Study JLB 1993) \$91,000

Out of Pocket Steam Cost = Coal + electricity + chemicals + FW + waste water treatment + fly ash + cinder disposal

OPSC =  $\frac{2.91 \text{ million} + (45 \times 64,673) + \$173,000 + \$91,000 + \$24,500 + \$6,500 + 15,000 + 10,000}{1,107,382,000 \text{ lbs}}$   
Per Defense fuels, Geo. Tittsworth 5/95

=  $\frac{3.23 \text{ million}}{1,107.} = 2.92 \frac{\$}{1000 \text{ lbs}}$  3.75  $\frac{\$}{\text{Klbs}}$  Counting maintenance



**TARIFF I. P.  
(Industrial Power)**

AVAILABILITY OF SERVICE

Available to industrial and large commercial customers. Customers shall contract for a definite amount of electrical capacity in KW which shall be sufficient to meet normal maximum requirements but in no case shall the capacity contracted for be less than 3,000 KW. Contract capacities will be specified in multiples of 100 KW.

MONTHLY RATE

<u>Tariff Code</u>	<u>Service Voltage</u>	<u>Demand Charge per KW</u>	<u>Energy Charge per KWH</u>	<u>Service Charge</u>
322	Primary	\$ 8.70	2.302 cents	\$ 240.00
323	Subtransmission	\$ 7.79	2.269 cents	\$ 730.00
324	Transmission	\$ 7.60 <i>HDC</i>	2.241 cents	\$1,930.00 <i>HDC</i>

Reactive Demand Charge for each Kilovar of Lagging Reactive Demand  
in excess of 50 percent of the KW of monthly metered demand . . . . . \$ 0.75 per KVAR

MINIMUM CHARGE

This tariff is subject to a minimum monthly charge equal to the sum of the service charge, the product of the demand charge and the monthly billing demand and the fuel clause adjustment.

FUEL CLAUSE

When the unit cost of fuel in the charges for power purchased from Appalachian Power Company under Federal Energy Regulatory Commission rate schedule No. 23 is above or below a base unit price of 15.8563 mills per KWH, adjusted for losses, the bill for service shall be increased or decreased respectively at a rate per KWH equal to the amount that such cost of fuel is above or below the unit base cost of 15.8563 mills per KWH, adjusted for losses, applied to the KWH measured in the period for which the bill is rendered. The adjustment shall be based on the most recent calendar month for which fuel cost data is available.

PROMPT PAYMENT DISCOUNT

A discount of 1.5 percent will be allowed if account is paid in full within 15 days of date of bill.

DETERMINATION OF DEMAND

The billing demand in KW shall be taken each month as the single highest 30-minute integrated peak in KW as registered during the month by a demand meter or indicator, or, at the Company's option, as the highest registration of a thermal type demand meter or indicator, but the monthly billing demand so established shall in no event be less than 60% of the greater of (a) the customer's contract capacity or (b) the customer's highest previously established monthly billing demand during the past 11 months nor less than 3,000 KW.

The reactive demand in KVARs shall be taken each month as the single highest 30-minute integrated peak in KVARs as registered during the month by a demand meter or indicator, or, at the Company's option, as the highest registration of a thermal type demand meter or indicator.

METERED VOLTAGE

The rates set forth in this tariff are based upon the delivery and measurement of energy at the same voltage, thus measurement will be made at or compensated to the delivery voltage. At the sole discretion of the Company, such compensation may be achieved through the use of loss compensating equipment, the use of formulas to calculate losses or the application of multipliers to the metered quantities. In such cases, the metered KWH and KW values will be adjusted for billing purposes. If the Company elects to adjust KWH and KW based on multipliers, the adjustments shall be in accordance with the following:

1. Measurements taken at the low-side of a customer-owned transformer will be multiplied by 1.01.
2. Measurements taken at the high-side of a Company-owned transformer will be multiplied by 0.98.

Dated: October 30, 1992  
By: Michael J. Holzaepfel, President  
Kingsport, Tennessee

Effective: November 3, 1992  
Pursuant to an Order in  
Docket Number 92-04425

**SCOPE  
OF  
WORK**





DEPARTMENT OF THE ARMY  
MOBILE DISTRICT, CORPS OF ENGINEERS  
P. O. BOX 2288  
MOBILE, ALABAMA 36628-0001

**RECEIVED**  
Affiliated Engineers SE, Inc.

APR 10 1995

Route to CO 4/10/95  
CC: 1015

April 4, 1995

REPLY TO  
ATTENTION OF:

A-E Contracts  
Section

Affiliated Engineers SE, Inc.  
Mr Carl L. Osberg  
3300 SW Archer Road  
Gainesville, FL 32608-1731

Gentlemen:

We have a requirement for a Limited Energy Study for Area B Nitric Acid Production Facilities at Holston AAP, TN, in accordance with the enclosed Scope of Work and as will be further defined at the pre-study conference on April 26 at Holston. It is proposed that this work be accomplished by delivery order under Contract Number DACA01-94-D-0007.

You are requested to submit your proposal for accomplishing this work by May 10, 1995. Your proposal should be addressed as follows:

District Engineer  
U. S. Army Engineer District, Mobile  
Attention: CESAM-EN-MN/Mr. Dan Mizelle  
Post Office Box 2288  
Mobile, Alabama 36628-0001

You are cautioned that no services for which an additional cost or fee will be charged should be furnished without the prior written authorization of the Contracting Officer.

Please contact Mr. Roger D. Baer at 205/441-5493 if you have any questions concerning this matter.

Sincerely,

O. B. Anderson  
Authorized Representative  
of the Contracting Officer

SCOPE OF WORK  
FOR A  
LIMITED ENERGY STUDY  
AREA B NITRIC ACID PRODUCTION FACILITIES  
HOLSTON ARMY AMMUNITION PLANT, TENNESSEE

Performed as part of the  
ENERGY ENGINEERING ANALYSIS PROGRAM (EEAP)

SCOPE OF WORK  
FOR A  
LIMITED ENERGY STUDY

AREA B NITRIC ACID PRODUCTION FACILITIES  
HOLSTON ARMY AMMUNITION PLANT, TENNESSEE

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5. PROJECT DOCUMENTATION
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  - 5.2 Non-ECIP Projects
  - 5.3 Nonfeasible ECOs
6. DETAILED SCOPE OF WORK
7. WORK TO BE ACCOMPLISHED
  - 7.1 Perform a Limited Site Survey
  - 7.2 Evaluate Selected ECOs
  - 7.3 Combine ECOs into Recommended Projects
  - 7.4 Submittals, Presentations and Reviews

ANNEXES

- A - DETAILED SCOPE OF WORK
- B - EXECUTIVE SUMMARY GUIDELINE
- C - REQUIRED DD FORM 1391 DATA

1. BRIEF DESCRIPTION OF WORK: The Architect-Engineer (AE) shall:

1.1 Perform a limited site survey of specific buildings or areas to collect all data required to evaluate the specific ECOs included in this study.

1.2 Evaluate specific ECOs to determine their energy savings potential and economic feasibility.

1.3 Provide project documentation for recommended ECOs as detailed herein.

1.4 Prepare a comprehensive report to document all work performed, the results and all recommendations.

2. GENERAL

2.1 This study is limited to the evaluation of the specific buildings, systems, or ECOs listed in Annex A, DETAILED SCOPE OF WORK.

2.2 The information and analysis outlined herein are considered to be minimum requirements for adequate performance of this study.

2.3 For the buildings, systems or ECOs listed in Annex A, all methods of energy conservation which are reasonable and practical shall be considered, including improvements of operational methods and procedures as well as the physical facilities. All energy conservation opportunities which produce energy or dollar savings shall be documented in this report. Any energy conservation opportunity considered infeasible shall also be documented in the report with reasons for elimination.

2.4 The study shall consider the use of all energy sources applicable to each building, system, or ECO.

2.5 The "Energy Conservation Investment Program (ECIP) Guidance", described in letter from DAIM-FDF-U, dated 10 Jan 1994 establishes criteria for ECIP projects and shall be used for performing the economic analyses of all ECOs and projects. The program, Life Cycle Cost In Design (LCCID), has been developed for performing life cycle cost calculations in accordance with ECIP guidelines and is referenced in the ECIP Guidance. If any program other than LCCID is proposed for life cycle cost analysis, it must use the mode of calculation specified in the ECIP Guidance. The output must be in the format of the ECIP LCCA summary sheet, and it must be submitted for approval to the Contracting Officer.

2.6 The following definitions apply to terms used in this scope of work:

2.6.1 "Contracting Officer", "Contracting Officer's Representative", or Government's Representative" refer to the contracting office of the Mobile District, U. S. Army Corps of Engineers.

2.6.2 "Installation Commander", or "Installation Representative" refer to the military commander of Holston Army Ammunition Plant.

2.6.3 "Plant Manager", Operating Contractor", or "Operating Contractor's Representative" refer to the Holston Defense Corporation, which operates Holston Army Ammunition Plant under contract to the U. S. Army.

2.7 Energy conservation opportunities determined to be technically and economically feasible shall be developed into projects acceptable to installation personnel. This may involve combining similar ECOs into larger packages which will qualify for ECIP or O&M funding, and determining in coordination with installation personnel the appropriate packaging and implementation approach for all feasible ECOs.

2.7.1 Projects which qualify for ECIP funding shall be identified, separately listed, and prioritized by the Savings to Investment Ratio (SIR).

2.7.2 All feasible non-ECIP projects shall be ranked in order of highest to lowest SIR.

2.8 Metric Reporting Requirements: In this study, the analyses of the ECOs may be performed using English or Metric units as long as they are consistent throughout the report. The final results of energy savings for individual recommended projects and for the overall study will be reported in units of MegaBTU per year and in MegaWattHours per year. Paragraph 7.4.2 details requirements for the contents of the final submittal.

### 3. PROJECT MANAGEMENT

3.1 Project Managers. The AE shall designate a project manager to serve as a point of contact and liaison for work required under this contract. Upon award of this contract, the individual shall be immediately designated in writing. The AE's designated project manager shall be approved by the Contracting Officer prior to commencement of work. This designated individual shall be responsible for coordination of work required under this contract. The Contracting Officer will designate a project manager to serve as the Government's point of contact and liaison for all work required under this contract. This individual will be the Government's representative.

#### 3.2 Installation Assistance.

3.2.1. The Installation Commander will designate an individual to coordinate between the AE and the Holston Defense Corporation. This individual will be the Installation Representative, and all correspondence with Holston Army Ammunition Plant will be addressed to his attention.

3.2.2. The Plant Manager will designate an individual to assist the AE in obtaining information and establishing contacts necessary to accomplish the work required under this contract. This individual will be the Operating Contractor's Representative.

3.3 Public Disclosures. The AE shall make no public announcements or disclosures relative to information contained or developed in this contract, except as authorized by the Contracting Officer.

3.4 Meetings. Meetings will be scheduled whenever requested by the AE or the Contracting Officer for the resolution of questions or problems encountered in the performance of the work. The AE's project manager and the Government's representative shall be required to attend and participate in all meetings pertinent to the work required under this contract as directed by the Contracting Officer. These meetings, if necessary, are in addition to the presentation and review conferences.

3.5 Site Visits, Inspections, and Investigations. The AE shall visit and inspect/investigate the site of the project as necessary and required during the preparation and accomplishment of the work.

### 3.6 Records

3.6.1 The AE shall provide a record of all significant conferences, meetings, discussions, verbal directions, telephone conversations, etc., with Government representative(s) relative to this contract in which the AE and/or designated representative(s) thereof participated. These records shall be dated and shall identify the contract number, delivery order number, participating personnel, subject discussed and conclusions reached. The AE shall forward to the Contracting Officer within ten calendar days, a reproducible copy of the records.

3.6.2 The AE shall provide a record of requests for and/or receipt of Government-furnished material, data, documents, information, etc., which if not furnished in a timely manner, would significantly impair the normal progression of the work under this contract. The records shall be dated and shall identify the contract number and modification number, if applicable. The AE shall forward to the Contracting Officer within ten calendar days, a reproducible copy of the record of request or receipt of material.

3.7 Interviews. The AE and the Government's representative shall conduct entry and exit interviews with the Plant Manager before starting work at the installation and after completion of the field work. The Government's representative shall schedule the interviews at least one week in advance.

3.7.1 Entry. The entry interview shall describe the intended procedures for the survey and shall be conducted prior to commencing work at the facility. As a minimum, the interview shall cover the following points:

- a. Schedules.
- b. Names of energy analysts who will be conducting the site survey.
- c. Proposed working hours.
- d. Support requirements from Holston Defense Corporation (HDC).

3.7.2 Exit. The exit interview shall briefly describe the items surveyed and probable areas of energy conservation. The interview shall also solicit input and advice from the Plant Manager.

4. SERVICES AND MATERIALS. All services, materials (except those specifically enumerated to be furnished by the Government), labor, supervision and travel necessary to perform the work and render the data required under this contract are included in the lump sum price of the contract.

5. PROJECT DOCUMENTATION. All energy conservation opportunities which the AE has considered shall be included in one of the following categories and presented in the report as such:

5.1 ECIP Projects. To qualify as an ECIP project, an ECO, or several ECOs which have been combined, must have a construction cost estimate greater than \$300,000, a Savings to Investment Ratio (SIR) greater than 1.25 and a simple payback period of less than ten years. The overall project and each discrete part of the project shall have an SIR greater than 1.25. All projects meeting the above criteria shall be arranged as specified in paragraph 2.7.1 and shall be provided with programming documentation. Programming documentation shall consist of a DD Form 1391 and life cycle cost analysis (LCCA) summary sheet(s) (with necessary backup data to verify the numbers presented). A life cycle cost analysis summary sheet shall be developed for each ECO and for the overall project when more than one ECO are combined. The energy savings for projects consisting of multiple ECOs must take into account the synergistic effects of the individual ECOs.

5.2 Non-ECIP Projects. Projects which do not meet ECIP criteria with regard to cost estimate or payback period, but which have an SIR greater than 1.25 shall be documented. Projects or ECOs in this category shall be arranged as specified in paragraph 2.7.2 and shall be provided with the following documentation: the life cycle cost analysis (LCCA) summary sheet completely filled out, a description of the work to be accomplished, backup data for the LCCA, ie, energy savings calculations and cost estimate(s), and the simple payback period. The energy savings for projects consisting of multiple ECOs must take into account the synergistic effects of the individual ECOs. In addition these projects shall have the necessary documentation prepared, as required by the Government's representative, for one of the following categories:

5.2.1. Federal Energy Management Program (FEMP) Projects. A FEMP (or O&M Energy) project is one that results in needed maintenance or repair to an existing facility, or replaces a failed or failing existing facility, and also results in energy savings. The criteria are similar to the criteria for ECIP projects, ie,  $SIR \geq 1.25$ , and simple payback period of less than ten years. Projects with a construction cost estimate up to \$1,000,000 shall be documented as outlined in par 5.2 above; projects over \$1,000,000 shall be documented on 1391s. In the FEMP program, a system may be defined as "failed or failing" if it is inefficient or technically obsolete. However, if this strategy is used to justify a proposed project, the equipment to be replaced must have been in use for at least three years.

5.2.2. Low Cost/No Cost Projects. These are projects which the Plant Manager can perform using his resources. Documentation shall be as required by the Plant Manager.

5.3 Nonfeasible ECOs. All ECOs which the AE has considered but which are not feasible, shall be documented in the report with reasons and justifications showing why they were rejected.

6. DETAILED SCOPE OF WORK. The Detailed Scope of Work may be found in Annex A.

7. WORK TO BE ACCOMPLISHED.

7.1 Perform a Limited Site Survey. The AE shall obtain all necessary data to evaluate the ECOs or projects by conducting a site survey. The AE shall document his site survey on forms developed for the survey, or standard forms, and submit these completed forms as part of the report. All test and/or measurement equipment shall be properly calibrated prior to its use.

7.2 Evaluate Selected ECOs. The AE shall analyze the ECOs listed in Annex A. These ECOs shall be analyzed in detail to determine their feasibility. Savings to Investment Ratios (SIRs) shall be determined using current ECIP guidance. The AE shall provide all data and calculations needed to support the recommended ECO. All assumptions and engineering equations shall be clearly stated. Calculations shall be prepared showing how all numbers in the ECO were figured. Calculations shall be an orderly step-by-step progression from the first assumption to the final number. Descriptions of the products, manufacturers catalog cuts, pertinent drawings and sketches shall also be included. A life cycle cost analysis summary sheet shall be prepared for each ECO and included as part of the supporting data.

7.3 Combine ECOs Into Recommended Projects. During the Interim Review Conference, as outlined in paragraph 7.4.1, the AE will be advised of the Plant Manager's preferred packaging of recommended ECOs into projects for implementation. Some projects may be a combination of several ECOs, and others may contain only one. These projects will be evaluated and arranged as outlined in



paragraphs 5.1, 5.2, and 5.3. Energy savings calculations shall take into account the synergistic effects of multiple ECOs within a project and the effects of one project upon another. The results of this effort will be reported in the Final Submittal per par 7.4.2.

7.4 Submittals, Presentations and Reviews. The work accomplished shall be fully documented by a comprehensive report. The report shall have a table of contents and shall be indexed. Tabs and dividers shall clearly and distinctly divide sections, subsections, and appendices. All pages shall be numbered. Names of the persons primarily responsible for the project shall be included. The AE shall give a formal presentation of the interim submittal to installation, command, and other Government personnel. Slides or view graphs showing the results of the study to date shall be used during the presentation. During the presentation, the personnel in attendance shall be given ample opportunity to ask questions and discuss any changes deemed necessary to the study. A review conference will be conducted the same day, following the presentation. Each comment presented at the review conference will be discussed and resolved or action items assigned. It is anticipated that the presentation and review conference will require approximately one working day. The presentation and review conference will be at the installation on the date agreeable to the Plant Manager, the AE and the Government's representative. The Contracting Officer may require a resubmittal of any document(s), if such document(s) are not approved because they are determined by the Contracting Officer to be inadequate for the intended purpose.

7.4.1 Interim Submittal. An interim report shall be submitted for review after the field survey has been completed and an analysis has been performed on all of the ECOs. The report shall indicate the work which has been accomplished to date, illustrate the methods and justifications of the approaches taken and contain a plan of the work remaining to complete the study. Calculations showing energy and dollar savings, SIR, and simple payback period of all the ECOs shall be included. The results of the ECO analyses shall be summarized by lists as follows:

a. All ECOs eliminated from consideration shall be grouped into one listing with reasons for their elimination as discussed in par 5.3.

b. All ECOs which were analyzed shall be grouped into two listings, recommended and non-recommended, each arranged in order of descending SIR. These lists may be subdivided by building or area as appropriate for the study. The AE shall submit the Scope of Work and any modifications to the Scope of Work as an appendix to the report. A narrative summary describing the work and results to date shall be a part of this submittal. At the Interim Submittal and Review Conference, the Government's and AE's representatives shall coordinate with the Plant Manager to provide the AE with direction for packaging or combining ECOs for programming purposes and also indicate the fiscal year for which the

programming or implementation documentation shall be prepared. The survey forms completed during this audit shall be submitted with this report. The survey forms only may be submitted in final form with this submittal. They should be clearly marked at the time of submission that they are to be retained. They shall be bound in a standard three-ring binder which will allow repeated disassembly and reassembly of the material contained within.

7.4.2 Final Submittal. The AE shall prepare and submit the final report when all sections of the report are 100% complete and all comments from the interim submittal have been resolved. The AE shall submit the Scope of Work for the study and any modifications to the Scope of Work as an appendix to the submittal. The report shall contain a narrative summary of conclusions and recommendations, together with all raw and supporting data, methods used, and sources of information. The report shall integrate all aspects of the study. The recommended projects, as determined in accordance with paragraph 5, shall be presented in order of priority by SIR. The lists of ECOs specified in paragraph 7.5.1 shall also be included for continuity. The final report and all appendices shall be bound in standard three-ring binders which will allow repeated disassembly and reassembly. The final report shall be arranged to include:

a. An Executive Summary to give a brief overview of what was accomplished and the results of this study using graphs, tables and charts as much as possible (See Annex B for minimum requirements).

b. The narrative report describing the problem to be studied, the approach to be used, and the results of this study.

c. Documentation for the recommended projects (includes LCCA Summary Sheets).

d. Appendices to include as a minimum:

- 1) Energy cost development and backup data
- 2) Detailed calculations
- 3) Cost estimates
- 4) Computer printouts (where applicable)
- 5) Scope of Work

## ANNEX A

### DETAILED SCOPE OF WORK

1. The facilities to be studied in this contract are used for the production of nitric acid in Area B at Holston Army Ammunition Plant (HSAAP) in Kingsport, Tennessee. Holston Army Ammunition Plant is a government-owned, contractor-operated (GOCO) facility. The operating contractor is the Holston Defense Corporation (HDC). For reasons of safety and security, access to the plant is controlled. Temporary passes will be required for both personnel and vehicle access.

a. A one-week notice should be given by the AE prior to any visit. This time will be needed to make the necessary arrangements for the visit.

b. The AE should submit a list of the equipment and instruments they plan to use prior to their arrival. Because of the nature of HSAAP operations, safety regulations prohibit and restrict the use of some equipment on the installation. Having a list of the equipment to be used beforehand, HSAAP will be better prepared at the entrance interview to address the regulations pertaining to the equipment to be used. This will also facilitate coordination of the inspection and permitting of the equipment.

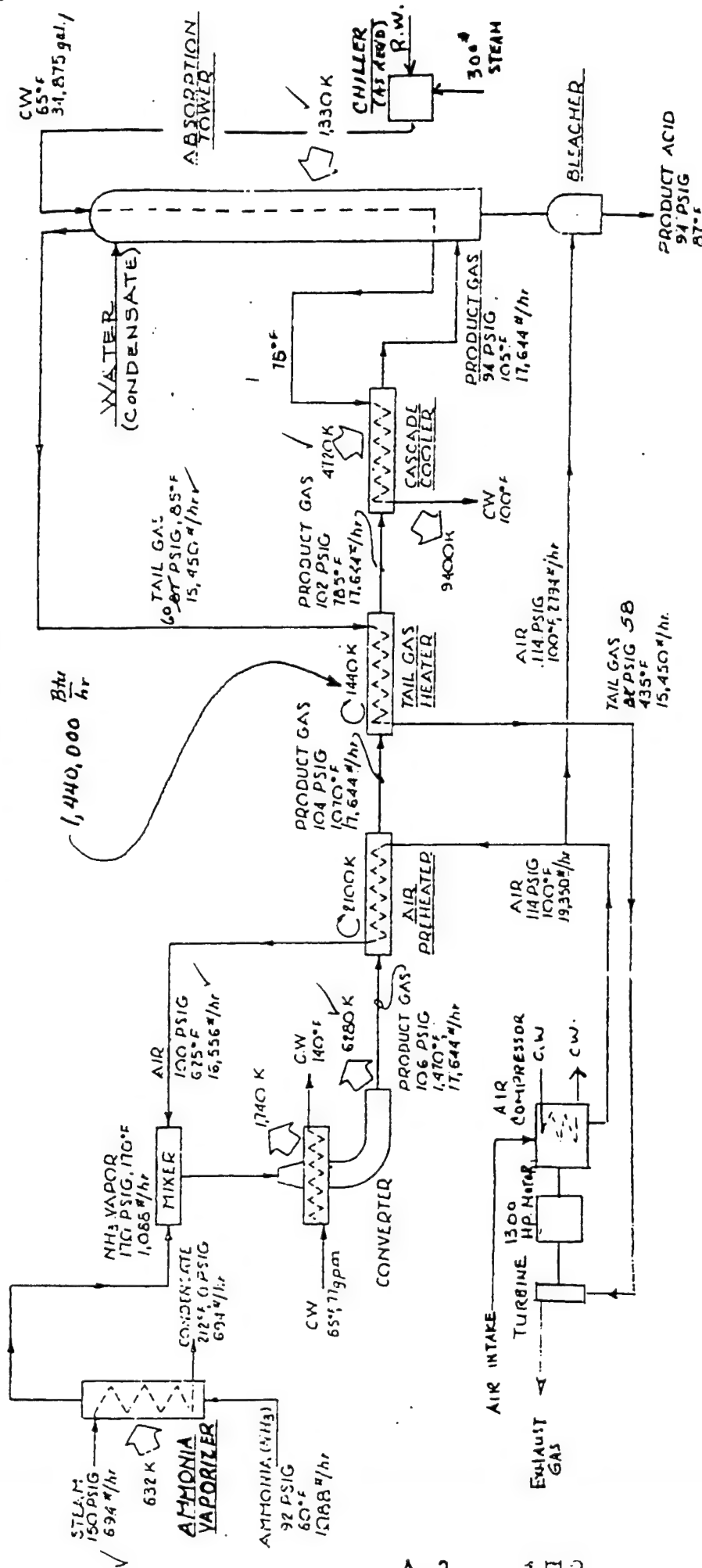
2. The following persons have been designated as points of contact and liaison for all work required under this contract. Mr. Scott Shelton shall be the Installation Representative, and Mr. J. L. Bouchillon shall be the Operating Contractor's Representative.

3. Completion and Payment Schedule: The following schedule shall be used as a guide in approving payments on this contract. The final report for this study shall be due not later than 180 days after Notice to Proceed.

<u>MILESTONE</u>	<u>PERCENT OF CONTRACT AMOUNT AUTHORIZED FOR PAYMENT</u>
Completion of Field Work	25
Receipt of Interim Submittal	75
Completion of Interim Presentation & Review	85
Receipt of Final Report	100

4. Purpose and Background: The purpose of this study is to identify and evaluate Energy Conservation Opportunities (ECOs) for the Ammonia Oxidation Process (AOP), which produces weak nitric acid. Figure 16 on page A-2 illustrates the AOP process. The chemical reactions utilized in the AOP are exothermic, producing large quantities of hot gases. Large amounts of cooling water are also used to cool and condense water vapor in the gases. Electrical energy is used to compress air for the process. Some heat and mechanical energy are already recovered

# ENERGY BALANCE-BLDG. 302-B NITRIC ACID MANUFACTURING



AS BUILT JAN 1995

HOLSTON ARMY AMMUNITION PLANT  
HOLSTON DEFENSE CORPORATION  
KINGSPORT, TENN.  
BLDG. 302-B, NITRIC ACID MFG.

DRAWN-PB  
DATE-1-14-78  
APP'D-1986  
SK-2286

FIGURE 16

in the process. However, there appears to be room for improvement in the process or by using recovered heat in nearby facilities. Building 302-B houses four 50-ton/day AOP units. Each AOP unit has an air compressor, which is driven by a 1300-HP electric motor. The motor is assisted by a gas turbine, which is driven by the tail gas from the process. At the present production level, one 50-TPD unit operates four continuous 24-hour days twice per month.

→ 5. The AE is encouraged to propose and analyze any ECOs which he believes may save energy, water, or dollars. The AE must become familiar with the process and with the capabilities and limitations of the existing equipment. Due to the limited resources available, proposed ECOs should not impose additional maintenance and operation requirements. In addition to ECOs proposed by the AE, the following ECOs will be evaluated:

a. Since 300 psig steam is available, revise air compressor turbine drive to steam. There may be variations on this ECO, such as using 300 psig steam exclusively (which might require a different turbine) or using steam (at 300 psig or at a reduced pressure) in the existing turbine to assist the electric motor.

b. Use the product gas leaving the Air Preheater (Fig 16) to generate steam. Depending on the pressure of the steam generated, the gas could be cooled to perhaps as low as 400 degF. The steam thus generated could be used to drive (or assist in driving) the air compressor, or it could be used to vaporize ammonia, or for heating at the 302-B tank farm.

c. Identify and evaluate the possibility of water conservation at the cascade coolers and at other points in the process.

6. Government-furnished information. The following documents will be furnished to the AE:

a. Energy Conservation Investment Program (ECIP) Guidance, dated 10 Jan 1994 and the latest revision with current energy prices and discount factors for life cycle cost analysis.

b. AR 415-15, 1 Jan 84, Military Construction, Army (MCA) Program Development

c. TM5-800-2, Cost Estimates, Military Construction.

d. Tri-Service Military Construction Program (MCP) Index, dated day/month/year.

e. As-built drawings and process descriptions with quantitative data for the AOP facilities.

8. A computer program titled Life Cycle Costing in Design (LCCID) is available from the BLAST Support Office in Urbana, Illinois for a nominal fee. This computer program can be used for performing the economic calculations for ECIP and non-ECIP ECOS. The AE is encouraged to obtain and use this computer program. The BLAST Support Office can be contacted at 144 Mechanical Engineering Building, 1206 West Green Street, Urbana, Illinois 61801. The telephone number is (217) 333-3977 or (800) 842-5278.

9. Direct Distribution of Submittals. The AE shall make direct distribution of correspondence, minutes, report submittals, and responses to comments as indicated by the following schedule:

AGENCY	EXECUTIVE SUMMARIES REPORTS FIELD NOTES CORRESPONDENCE			
Holston Army Ammunition Plant ATTN: SMCHO-EN (Mr Shelton) Kingsport, TN 37660-9982	3	3	1**	1
US AMC I & SA ATTN: AMXEN-C (Mr Nache) Rock Island, IL, 61299-7190	1	1	-	-
Commander US Army Corps of Engineers ATTN: CEMP-ET (Mr Gentil) 20 Massachusetts Avenue NW Washington, DC, 20314-1000	1*	-	-	-
USAED, South Atlantic ATTN: CESAD-EN-TE (Mr Baggette) 77 Forsyth Street, SW Atlanta, GA 30335-6801	1	1	-	-
USAED, Mobile ATTN: CESAM-EN-DM (Battaglia) PO Box 2288 Mobile, AL 36628-0001	2	2	1**	1
US Army Logistics Evaluation Agency ATTN: LOEA-PL (Mr Keath) New Cumberland Army Depot New Cumberland, PA, 17070 - 5007	1*	-	-	-

\* Receives Executive Summary of final report only.

\*\* Field Notes submitted in final form at interim submittal.

## ANNEX B

### EXECUTIVE SUMMARY GUIDELINE

1. Introduction.
2. Building Data (types, number of similar buildings, sizes, etc.)
3. Present Energy Consumption of Buildings or Systems Studied.
  - o Total Annual Energy Used.
  - o Source Energy Consumption.
    - Electricity - KWH, Dollars, MBTU
    - Coal - TONS, Dollars, MBTU, MWH
    - Natural Gas - THERMS, Dollars, MBTU, MWH
    - Other - QTY, Dollars, MBTU, MWH

4. Energy Conservation Analysis.
  - o ECOs Investigated.
  - o ECOs Recommended.
  - o ECOs Rejected. (Provide economics or reasons)
  - o ECIP Projects Developed. (Provide list)\*
  - o Non-ECIP Projects Developed. (Provide list)\*
  - o Operational or Policy Change Recommendations.

\* Include the following data from the life cycle cost analysis summary sheet: the cost (construction plus SIOH), the annual energy savings (type and amount), the annual dollar savings, the SIR, the simple payback period and the analysis date.

6. Energy and Cost Savings.
  - o Total Potential Energy Savings in MegaBTU per year (and MegaWattHr per year) and first year dollar savings.
  - o Percentage of Energy Conserved.
  - o Energy Use and Cost Before and After the Energy Conservation Opportunities are Implemented.

ANNEX C

REQUIRED DD FORM 1391 DATA

To facilitate ECIP project approval, the following supplemental data shall be provided:

- a. In title block clearly identify projects as "ECIP."
- b. Complete description of each item of work to be accomplished including quantity, square footage, etc.
- c. A comprehensive list of buildings, zones, or areas including building numbers, square foot floor area, designated temporary or permanent, and usage (administration, patient treatment, etc.).
- d. List references, and assumptions, and provide calculations to support dollar and energy savings, and indicate any added costs.
  - (1) If a specific building, zone, or area is used for sample calculations, identify building, zone or area, category, orientation, square footage, floor area, window and wall area for each exposure.
  - (2) Identify weather data source.
  - (3) Identify infiltration assumptions before and after improvements.
  - (4) Include source of expertise and demonstrate savings claimed. Identify any special or critical environmental conditions such as pressure relationships, exhaust or outside air quantities, temperatures, humidity, etc.
- e. Claims for boiler efficiency improvements must identify data to support present properly adjusted boiler operation and future expected efficiency. If full replacement of boilers is indicated, explain rejection of alternatives such as replace burners, nonfunctioning controls, etc. Assessment of the complete existing installation is required to make accurate determinations of required retrofit actions.
- f. Lighting retrofit projects must identify number and type of fixtures, and wattage of each fixture being deleted and installed. New lighting shall be only of the level to meet current criteria. Lamp changes in existing fixtures is not considered an ECIP type project.



g. An ECIP life cycle cost analysis summary sheet as shown in the ECIP Guidance shall be provided for the complete project and for each discrete part included in the project. The SIR is applicable to all segments of the project. Supporting documentation consisting of basic engineering and economic calculations showing how savings were determined shall be included.

h. The DD Form 1391 face sheet shall include, for the complete project, the annual dollar and MBTU (MWH) savings, SIR, simple amortization period and a statement attesting that all buildings and retrofit actions will be in active use throughout the amortization period.

i. The calendar year in which the cost was calculated shall be clearly shown on the DD Form 1391.

j. For each temporary building included in a project, separate documentation is required showing (1) a minimum 10-year continuing need, based on the installation's annual real property utilization survey, for active building retention after retrofit, (2) the specific retrofit action applicable and (3) an economic analysis supporting the specific retrofit.

k. Nonappropriated funded facilities will not be included in an ECIP project without an accompanying statement certifying that utility costs are not reimbursable.

l. Any requirements required by ECIP guidance dated 10 Jan 1994 and any revisions thereto. Note that unescalated costs/savings are to be used in the economic analyses.

m. The five digit category number for all ECIP projects except for Family Housing is 80000. The category code number for Family Housing projects is 71100.

**MINUTES  
OF  
MEETINGS**

3300 SW Archer Road  
Gainesville, Florida 32608  
(904) 376-5500 • FAX (904) 375-3479

## MEETING NOTES

### HOLSTON AREA B ACID FACILITY STUDY

Project

KINGSPORT, TN

City, State

INTERIM REVIEW

Type of Meeting

11/30/95

Meeting Date

95094-00

Project #

December 1, 1995

Date

1 of 2

MAH

Page

PDL

Typist

Copies

Present

Representing

Tony Battaglia  
Scott Shelton  
Jerry Bouchillon  
Alex Fancher  
Paul Little  
Carl Osberg

US Army Corps of Engineers  
Holston AAP  
HDC  
HDC  
AESE  
AESE

The purpose of this meeting was to review the Interim Report and the following items were discussed.

1. Reviewed schematic flow diagram of process. Several corrections were noted.
2. AESE to revise energy inventory table and show sample calculations (pages 43-49).
3. ECO No. 1 - needs to be revised to reflect replacing of the existing tailgas turbine with a steam condensing turbine. Noise will be an issue to review if tail gas is going to be exhausted.
4. ECO No. 2 - correct steam output from 31,000 to 3,100 lbs/hr and review using steam to assist turbine.
5. AESE to create a new ECO utilizing insulated air preheater, tailgas heater and plantnium recovery filter, with a once through steam system to assist the turbines.
6. Look at possibility of eliminating/replacing cascade cooler.
7. Plantnium filter needs to be located prior to any waste heat boiler and cascade cooler.
8. Stainless steel needs to be 400 grade for any metals in contact with product gas. AESE to get price quotes from manufacturers for waste heat boiler.
9. Dowtherm A (eutectic mixture of Diphenyl Oxide and Diphenyl) is incompatible with the process if a leak were to occur, and is to be eliminated from consideration for an intermediate heat transfer fluid.
10. Utilizing a cooling tower will jeopardize Pollution Permits (ECO No. 3).
11. Existing chiller has capacity for operating only (2) units at once.
12. Add Conclusions and Recommendations to Executive Summary section of the report.

**Project Name:** Holston AAP Nitric Acid Production Facility

**Date:** December 22, 1995

**Project No.:** 95094-00

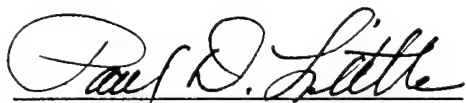
**Page No.:** 2 of 2

13. Starting turbine without tail gas uses 290 amps of electrical power when tail gas is added to turbine the electrical power drops to 220 amps.
14. AESE to investigate chiller revision from a direct-contact steam condenser to a steam surface condenser from which steam condensate can be recovered. Because chiller operates only 5 months out of year, evaluate production level at which this modification will qualify for ECIP.

The above constitutes the writer's understanding of the discussions of this meeting and conclusions reached. Corrections/errors should be noted to the writer within 5 working days.

By:

**AFFILIATED ENGINEERS SE, INC.**



FOR Carl L. Osberg, P.E.  
Vice President

3300 SW Archer Road  
Gainesville, Florida 32608  
(904) 376-5500 • FAX (904) 375-3479

## MEETING NOTES

HOLSTON AAP NITRIC ACID PRODUCTION FACILITY

95094-00

Project

Project #

HOLSTON, TN

August 22, 1995

City, State

Date

EXIT INTERVIEW

1 of 1

DA

Type of Meeting

Page

Typist

08/17/95 (AM)

Meeting Date

Copies

Present

Representing

Scott Shelton  
Alex Francher  
Carl Osberg  
Paul Little

SMCHO-EN  
HDC  
AESE  
AESE

The purpose of this meeting was to review the items surveyed and discuss probable areas of energy conservation. The following items were discussed.

Nitric Acid manufacturing process was observed in operation with absorption column #9 operating. Each of the four air compressors were operating, but only one of the four was being loaded. It was noted that compressed air final stage after cooler does not have dewpoint control or other control strategy. The steam jet refrigerating unit was confirmed to utilize a steam surface condenser.

The above constitutes the writer's understanding of the discussions of this meeting and conclusions reached. Corrections/errors should be noted to the writer within 5 working days.

By,



Paul Little, P.E.  
HVAC Project Engineer

3300 SW Archer Road

Gainesville, Florida 32608

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## MEETING NOTES

### HOLSTON AAP NITRIC ACID PRODUCTION FACILITY

95094-00

Project

Project #

HOLSTON, TN

July 11, 1995

City, State

Date

EXIT INTERVIEW

1 of 1

MAH

Type of Meeting

Page

Typist

07/07/95

CO

Meeting Date

Copies

Present

Representing

Scott Shelton  
Charlie Fowler  
Robert Barnes

SMCHO-EN  
HDC - Engineering  
AESE

The purpose of this meeting was to review the items surveyed and discuss probable areas of energy conservation. The following items were discussed.

1. Bob Barnes briefly reviewed the scope of work for this project. Some options available for saving energy, water or dollars for this project include:
  - Recover heat to generate steam or hot water to supplement or eliminate steam used to vaporize ammonia.
  - Recover heat to generate steam to be used to reduce existing steam used at chiller.
  - Reduce filtered riverwater used at cascade cooler by storing chilled water in a closed loop configuration.
  - Recover heat to generate steam to run turbine at air compressor to reduce electric motor use.
  - Recover hot condensate from vaporizer and/or chiller to be regenerated to steam with waste heat for use at vaporizer or chiller.
  - Use 300 psig or 150 psig steam from existing steam system to run a turbine at the air compressor to reduce or eliminate the electric motor usage.
2. Bob Barnes asked Mr. Fowler if there were any ideas for energy conservation which had been overlooked. Mr. Fowler was not aware of other potential energy saving concepts.
3. Mr. Fowler clarified the capacity of the steam jet chiller. The chiller was relocated from another process and is approximately sized to handle 2 AOP process streams and not 4 as originally estimated by AESE.

The above constitutes the writer's understanding of the discussions of this meeting and conclusions reached. Corrections/errors should be noted to the writer within 5 working days.

By:

AFFILIATED ENGINEERS SE, INC.

*Robert A. Barnes*

Robert A. Barnes, P.E.  
HVAC Project Engineer

3300 SW Archer Road

Gainesville, Florida 32608

(904) 376-5500 • FAX (904) 375-3479

## MEETING NOTES

HOLSTON AAP NITRIC ACID PRODUCTION FACILITY

95094-00

Project

HOLSTON, TN

Project #

July 11, 1995

City, State

ENTRY INTERVIEW

Date

1 of 1

MAH

Type of Meeting

07/05/95

Page

Typist

CO

Meeting Date

Copies

Present

Representing

Scott Shelton

SMCHO-EN

Jerry Bouchillon

HDC

Alex Fancher

HDC

Mike Richarme

AESE

Carl Osberg

AESE

Robert Barnes

AESE

The purpose of this meeting was to have an entry interview and the following items were discussed.

1. Mr. Jerry Bouchillon inquired as to the type of data needed to be furnished by HDC. AESE personnel requested information regarding: compressor intercooler water flow: Pump flows; pump curves; motor data; chiller capacity; and chiller steam flow and pressure.
2. Alex Fancher stated that manuals were available by Dupont which had technical data on the AOP process which could contain information useful for this project. The manuals would be located during the AESE field investigation to be reviewed for useful information.
3. Jerry Bouchillon would provide AESE with the name of the stainless steel fabricator who provided equipment for this facility to be used for pricing and special fabrication information.
4. AESE would conduct the field investigation today 07/05/95 instead of the document review listed in the AESE agenda. This would allow Mike Richarme to become familiar with the AOP Facility so he could shorten his field investigation time and depart this evening.
5. Jerry Bouchillon advised that mechanical and electrical drawings of the AOP Facility were downstairs in the engineering plan room. AESE personnel were invited to look through the drawings for relevant information for this project.

The above constitutes the writer's understanding of the discussions of this meeting and conclusions reached. Corrections/errors should be noted to the writer within 5 working days.

By:

AFFILIATED ENGINEERS SE, INC.

*Robert A. Barnes*

Robert A. Barnes, P.E.  
HVAC Project Engineer

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Gainesville, Florida 32608  
(904) 376-5500 • FAX (904) 375-3479

## MEETING NOTES

HOLSTON AAP NITRIC ACID PRODUCTION FACILITY

95094-00

Project

Project #

HOLSTON, TN

May 1, 1995

City, State

Date

PRE-NEGOTIATIONS

1 of 2

MAH

Type of Meeting

Page

Typist

04/26/95

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Meeting Date

Copies

Present

Representing

Tony Battaglia  
Jerry Bouchillon  
Scott Shelton  
Bob Lowe  
Robert Barnes  
Carl Osberg

US Army Corps of Engineers  
HDC  
SMCHO-EN  
HDC  
AESE  
AESE

The purpose of this meeting was to review the project scope and the following items were discussed.

1. HDC is investigating purchasing 100 lb steam from Tennessee-Eastman.
2. Acid production facility operates only 2 to 4 days/month but runs continuous during the 2 to 4 days. Currently run two units during this period. Investigate running one unit all week vs two units for 2 to 4 days. Staffing of facility needs to be considered.
3. A more detailed schematic diagram of the system is needed to better understand the system.
4. Steam cost is \$2.94/MBtu at present. Electrical cost is \$.03412/kWH.
5. Nitric acid production process was invented in 1935 and has been active at Holston since 1942. A newer more efficient process is now available and is also active at Holston. A new 300 ton/day unit is presently in use at HDC.
6. A waste heat boiler is a possible option to generate steam to run the air compressors to reduce the electric motor energy use.
7. Alex Fancher is contact point at acid production facility.
8. A steam jet ejector chiller is currently used to cool river water when water temperatures rise in the summer months.
9. Jerry Bouchillon to update flow diagram of process, provide P&I drawings of process, and provide air compressor curves. Data on turbines will be made available at entry interview.
10. Proposal to Corps may also include ideas/approach to project that is different than scope of work.
11. AESE to notify Corps prior to submitting proposal of any special consultants, testing, etc. that is going to be proposed.



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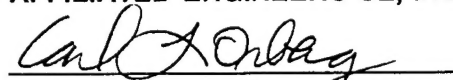
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The above constitutes the writer's understanding of the discussions of this meeting and conclusions reached. Corrections/errors should be noted to the writer within 5 working days.

By:

**AFFILIATED ENGINEERS SE, INC.**



Carl L. Osberg, P.E.  
Vice President